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Kume et al.

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(54) **INVERTER DEVICE AND MOTOR DRIVE SYSTEM**

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(73) Assignee: **KABUSHIKI KAISHA YASKAWA DENKI**, Kitakyushu-Shi (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 132 days.

(21) Appl. No.: **14/162,740**

(22) Filed: **Jan. 24, 2014**

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(30) **Foreign Application Priority Data**

Feb. 1, 2013 (JP) 2013-018808

(51) **Int. Cl.**

H02P 1/00	(2006.01)
H02P 3/00	(2006.01)
H02P 7/06	(2006.01)
H02P 25/18	(2006.01)
H02P 6/08	(2006.01)

(52) **U.S. Cl.**

CPC ***H02P 25/188*** (2013.01); ***H02P 6/08*** (2013.01)

(58) **Field of Classification Search**

CPC H02P 25/20; H02P 25/18; H02P 23/06; H02P 25/188; H02P 1/42; H02P 1/44; H02P 21/0035; H02P 21/04; H02P 27/026; H02P 27/06; H02P 29/0016; H02P 3/20; H02P 6/08; H02P 6/20; H01L 2924/0002

USPC 318/497, 504, 808, 400.21, 400.26

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,453,118	A *	6/1984	Phillips et al.	318/779
4,712,054	A *	12/1987	Boldt	318/758
5,216,343	A *	6/1993	Genheimer et al.	318/568.18
5,256,951	A *	10/1993	Nashiki et al.	318/575

(Continued)

FOREIGN PATENT DOCUMENTS

CN	102868347	1/2013
JP	06-225588	8/1994

(Continued)

OTHER PUBLICATIONS

Japanese Office Action for corresponding JP Application No. 2013-018808, Mar. 18, 2014.

(Continued)

Primary Examiner — Paul Ip

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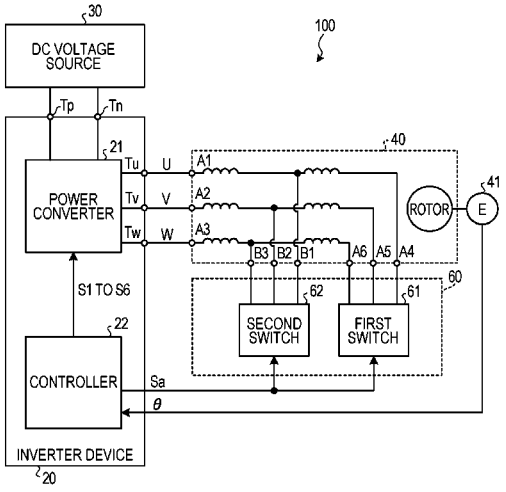
(57) **ABSTRACT**

An inverter device includes a power supply unit and a switch controller. The power supply unit supplies AC power to an AC motor whose electric characteristics in response to a rotation speed are switchable between low speed characteristics and high speed characteristics. The switch controller switches the electric characteristics of the AC motor. The switch controller executes switching control that alternately switches the electric characteristics of the AC motor between the low speed characteristics and the high speed characteristics on the basis of the rotation speed of the AC motor.

21 Claims, 15 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

5,821,722	A *	10/1998	Forbes et al.	318/696
5,883,488	A *	3/1999	Woodward	318/786
6,847,185	B2 *	1/2005	Kume et al.	318/732
7,084,600	B2 *	8/2006	Suzuki et al.	318/802
8,183,817	B2 *	5/2012	Higashikawa et al.	318/807
8,207,701	B2 *	6/2012	Tang et al.	318/808
8,269,450	B2 *	9/2012	Higashikawa et al.	318/771
2004/0195994	A1 *	10/2004	Kume et al.	318/807
2010/0237815	A1 *	9/2010	Higashikawa et al.	318/400.21
2011/0080131	A1	4/2011	Shimada et al.	
2012/0025779	A1 *	2/2012	Xu et al.	320/129
2012/0206083	A1 *	8/2012	Higashikawa et al.	318/808
2013/0009586	A1 *	1/2013	Chen et al.	318/504
2013/0221791	A1 *	8/2013	Tomohara et al.	310/198

FOREIGN PATENT DOCUMENTS

JP	2010-022165	1/2010
JP	2011-083069	4/2011
JP	2012-222848	11/2012

OTHER PUBLICATIONS

Osama et al. "A New Inverter Control Scheme for Induction Motor Drives Requiring Wide Speed Range", IEEE Transactions on Industry Applications, Jul./Aug. 1996, p. 938-944, vol. 32. No. 4.

Chinese Office Action for corresponding CN Application No. 201310737925.X, Nov. 16, 2015.

* cited by examiner

FIG. 1

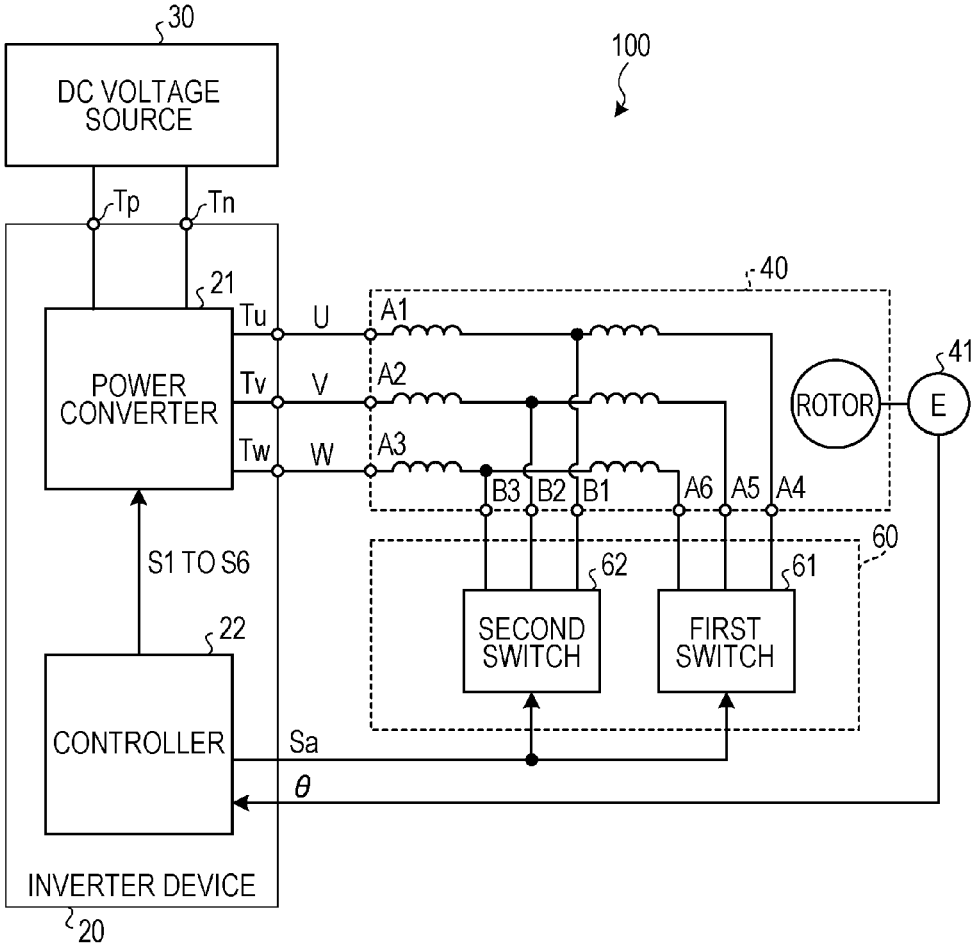

30
DC VOLTAGE SOURCE
100
Tp
Tn
21
40
POWER CONVERTER
Tu
U
A1
Tv
V
A2
Tw
W
A3
ROTOR
41
E
B3
B2
B1
A6
A5
A4
60
62
61
S1 TO S6
SECOND SWITCH
FIRST SWITCH
22
CONTROLLER
Sa
θ
INVERTER DEVICE
20

FIG. 2

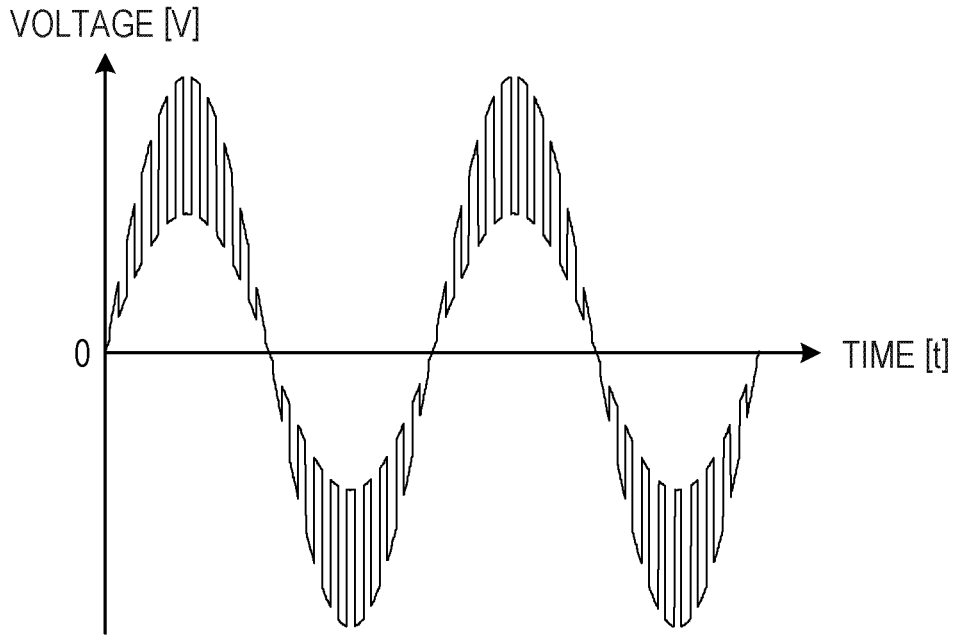


FIG. 3

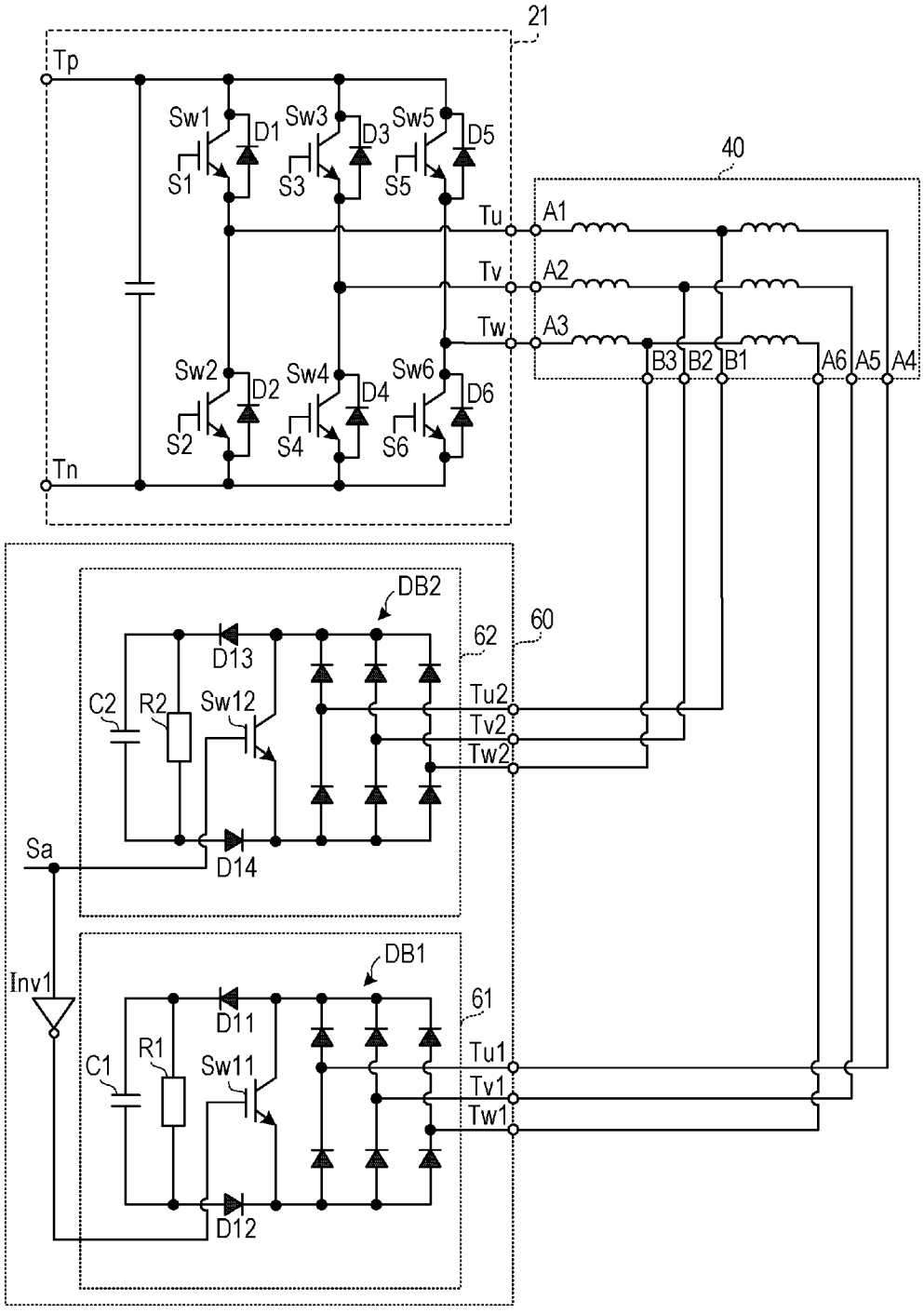

21
Tp
Sw1
D1
Sw3
D3
Sw5
D5
S1
S3
S5
40
Tu
A1
Tv
A2
Tw
A3
B3
B2
B1
A6
A5
A4
Sw2
D2
Sw4
D4
Sw6
D6
S2
S4
S6
Tn
DB2
62
60
D13
C2
R2
Sw12
Tu2
Tv2
Tw2
Sa
D14
DB1
Inv1
61
D11
R1
C1
Sw11
Tu1
Tv1
Tw1
D12

FIG. 4

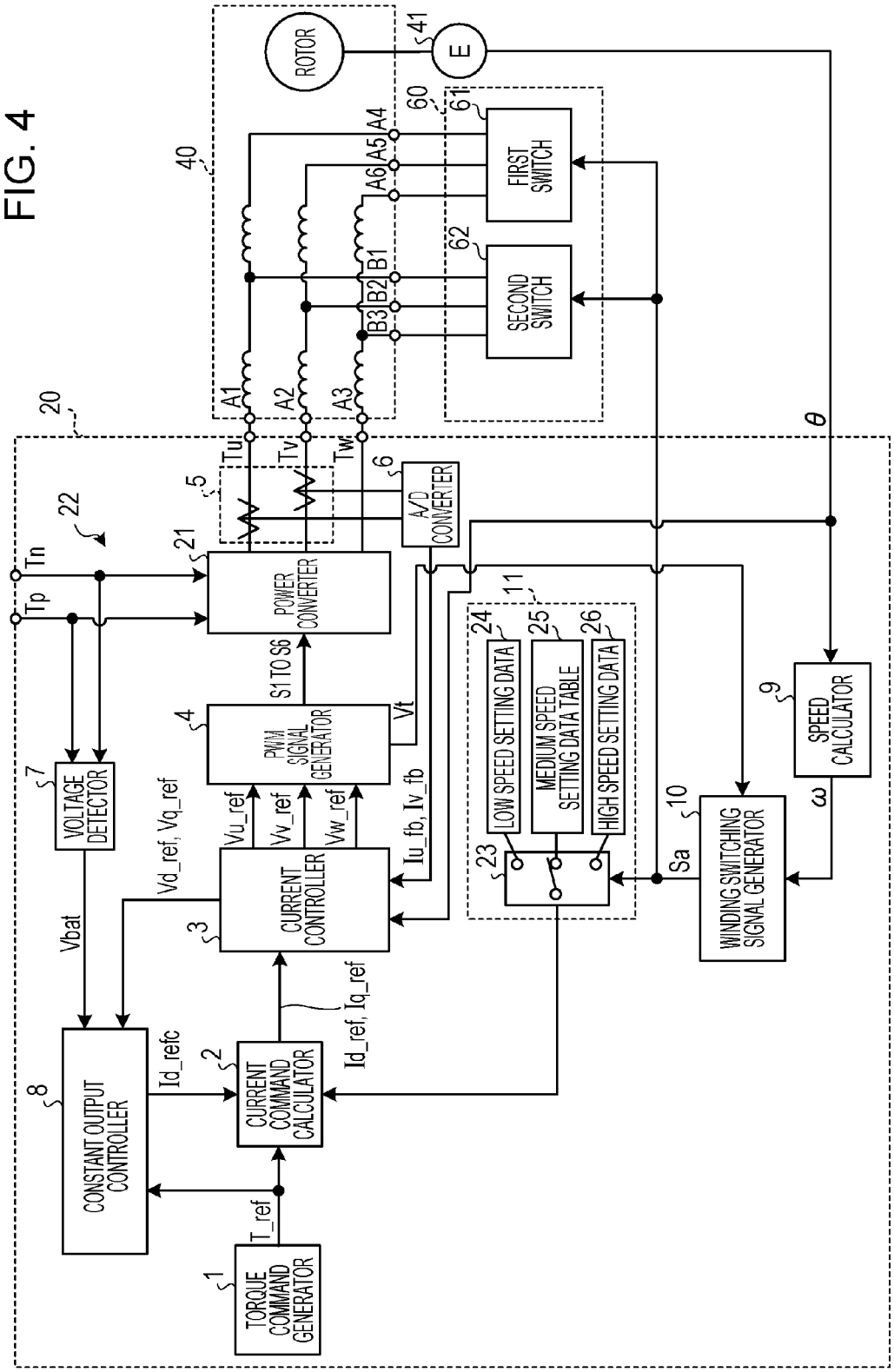

ROTOR
E
41
40
60
61
FIRST SWITCH
62
SECOND SWITCH
A1
A2
A3
A4
A5
A6
B1
B2
B3
20
θ
Tu
Tv
Tw
5
6
A/D CONVERTER
22
Tn
Tp
21
POWER CONVERTER
11
24
25
26
LOW SPEED SETTING DATA
MEDIUM SPEED SETTING DATA TABLE
HIGH SPEED SETTING DATA
9
SPEED CALCULATOR
S1 TO S6
4
PWM SIGNAL GENERATOR
Vt
7
VOLTAGE DETECTOR
Vu_ref
Vv_ref
Vw_ref
Iu_fb, Iv_fb
Vd_ref, Vq_ref
23
Sa
10
WINDING SWITCHING SIGNAL GENERATOR
ω
Vbat
3
CURRENT CONTROLLER
Id_ref, Iq_ref
8
CONSTANT OUTPUT CONTROLLER
Id_refc
2
CURRENT COMMAND CALCULATOR
T_ref
1
TORQUE COMMAND GENERATOR

FIG. 5

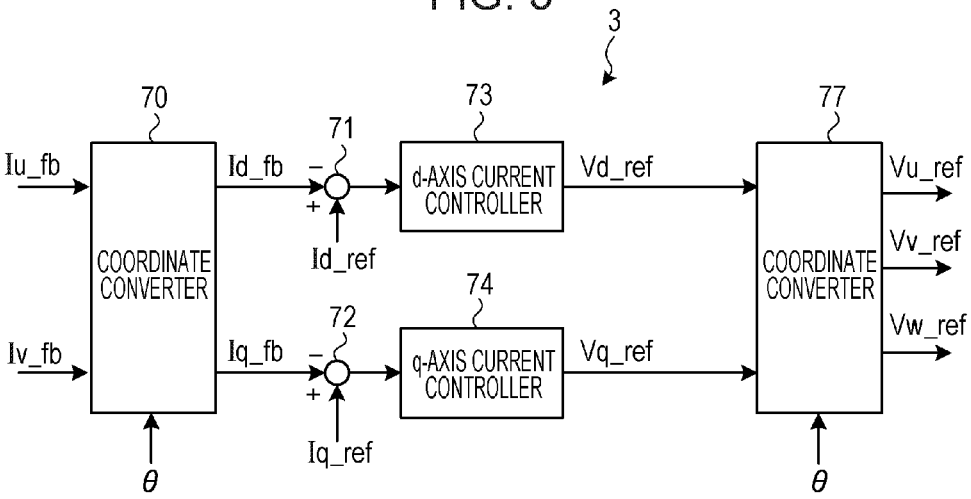

3
70
71
73
77
Iu_fb
Id_fb
d-AXIS CURRENT CONTROLLER
Vd_ref
Vu_ref
Vv_ref
Vw_ref
COORDINATE CONVERTER
Id_ref
74
72
Iv_fb
Iq_fb
q-AXIS CURRENT CONTROLLER
Vq_ref
Iq_ref
θ
θ

FIG. 6

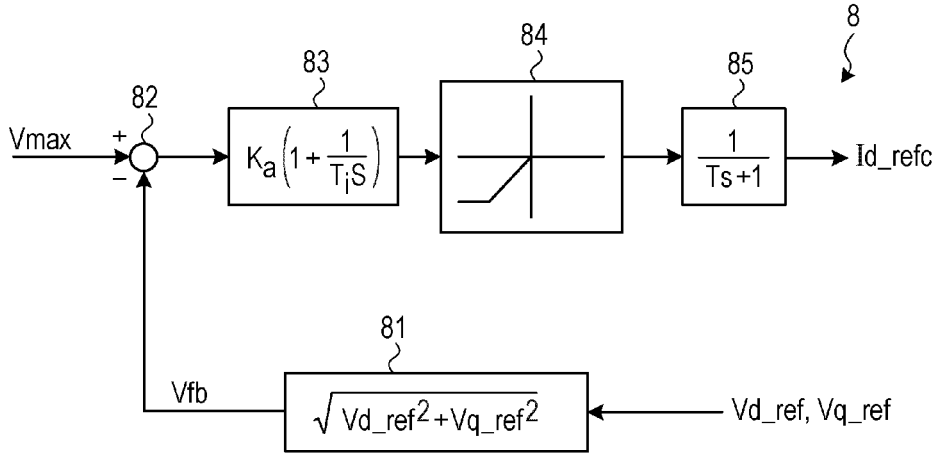

8
84
83
85
82
Vmax
$K_a\left(1+\frac{1}{T_iS}\right)$
$\frac{1}{Ts+1}$
Id_refc
81
Vfb
$\sqrt{Vd_ref^2+Vq_ref^2}$
Vd_ref, Vq_ref

FIG. 7

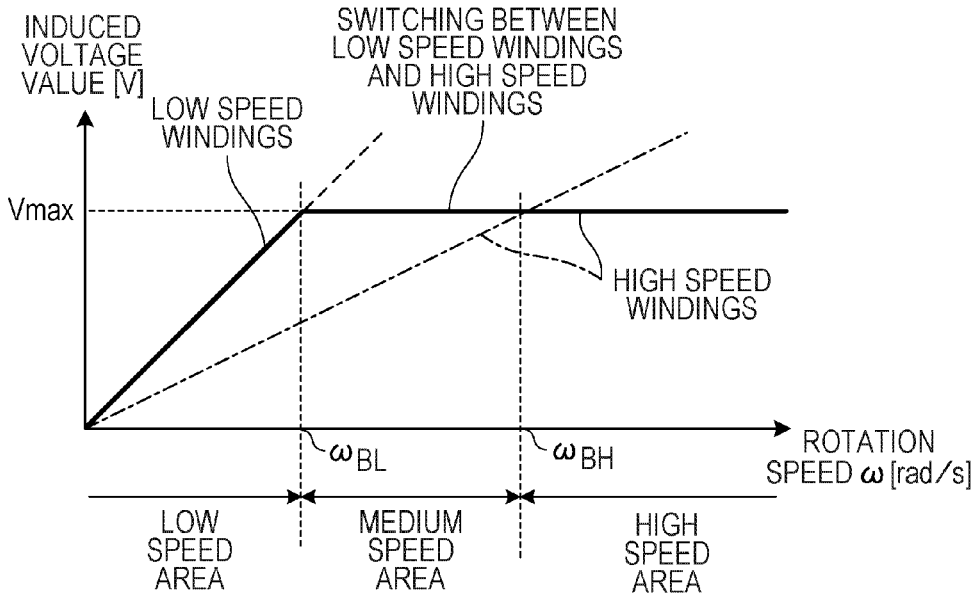

INDUCED VOLTAGE VALUE [V]
SWITCHING BETWEEN LOW SPEED WINDINGS AND HIGH SPEED WINDINGS
LOW SPEED WINDINGS
Vmax
HIGH SPEED WINDINGS
ωBL
ωBH
ROTATION SPEED ω [rad/s]
LOW SPEED AREA
MEDIUM SPEED AREA
HIGH SPEED AREA

FIG. 8

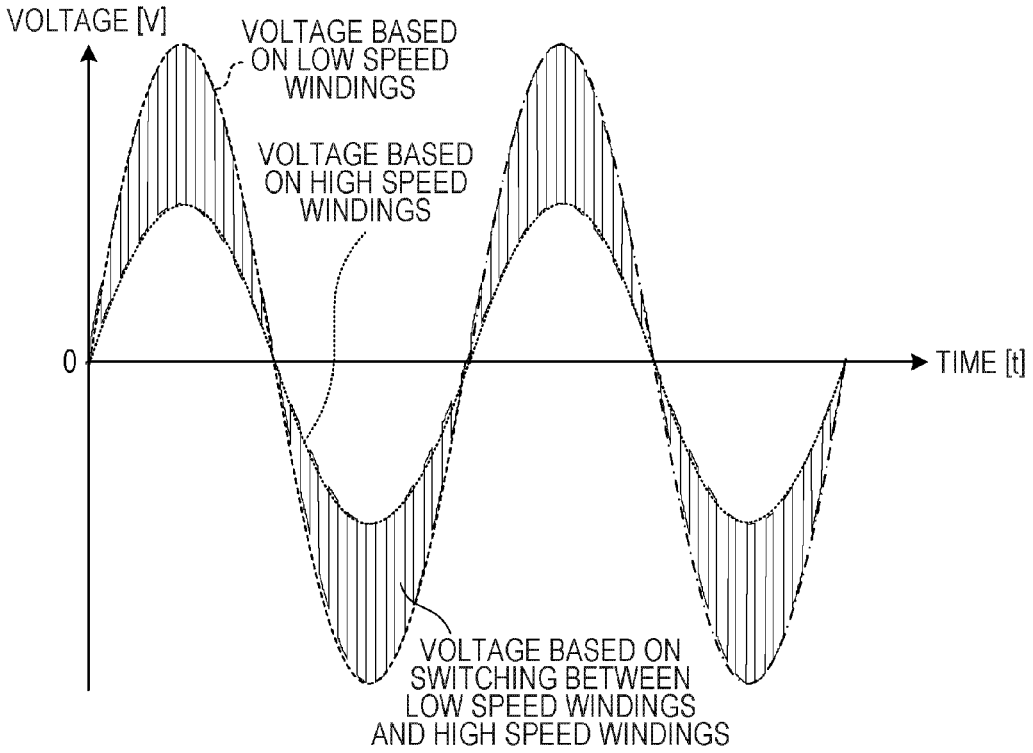

VOLTAGE [V]
VOLTAGE BASED ON LOW SPEED WINDINGS
VOLTAGE BASED ON HIGH SPEED WINDINGS
0
TIME [t]
VOLTAGE BASED ON SWITCHING BETWEEN LOW SPEED WINDINGS AND HIGH SPEED WINDINGS

FIG. 9

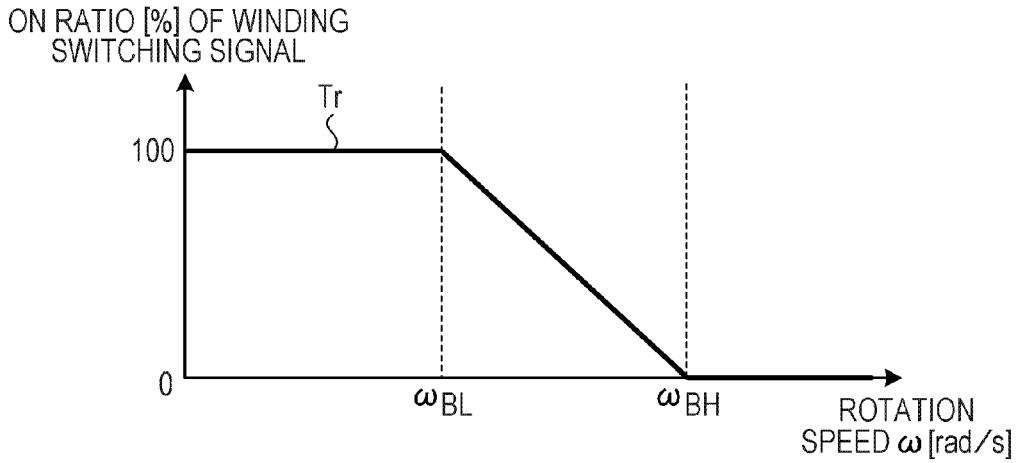

ON RATIO [%] OF WINDING SWITCHING SIGNAL
Tr
100
0
ωBL
ωBH
ROTATION SPEED ω [rad/s]

FIG. 10

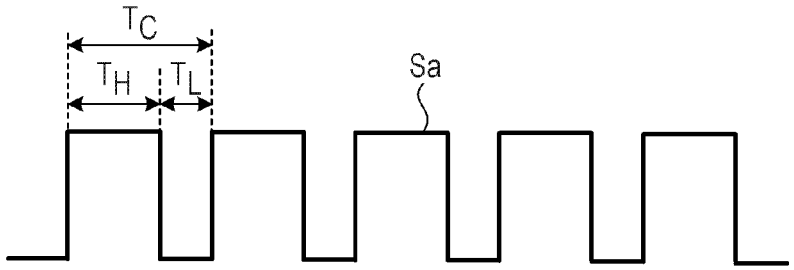

TC
TH
TL
Sa

FIG. 11

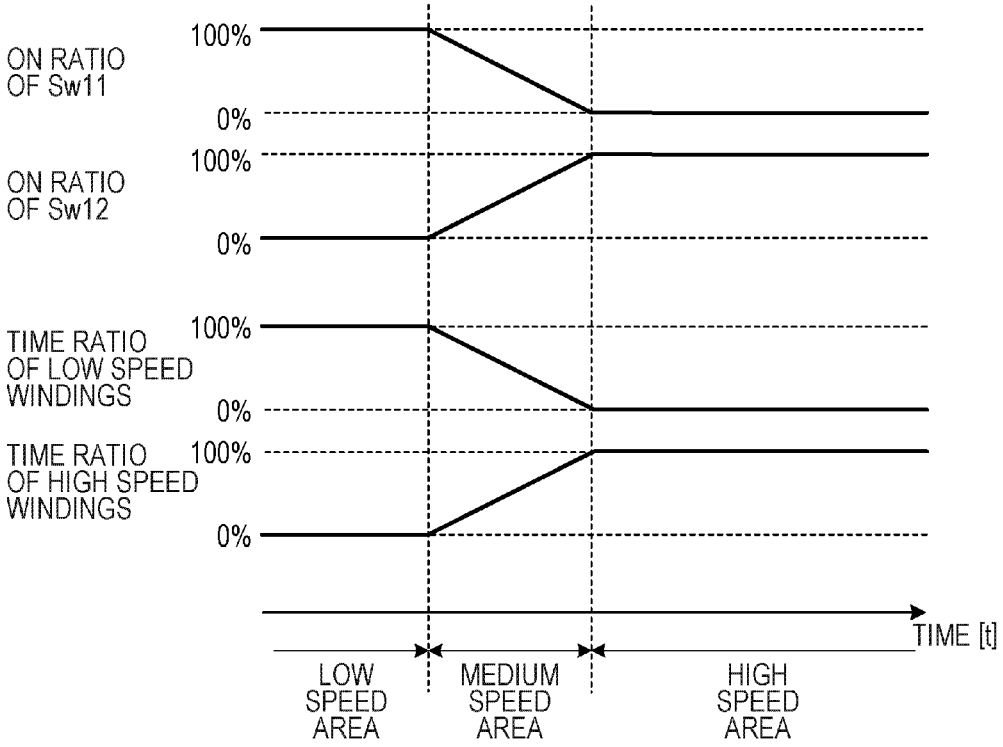

ON RATIO OF Sw11
100%
0%
ON RATIO OF Sw12
100%
0%
TIME RATIO OF LOW SPEED WINDINGS
100%
0%
TIME RATIO OF HIGH SPEED WINDINGS
100%
0%
TIME [t]
LOW SPEED AREA
MEDIUM SPEED AREA
HIGH SPEED AREA

FIG. 12

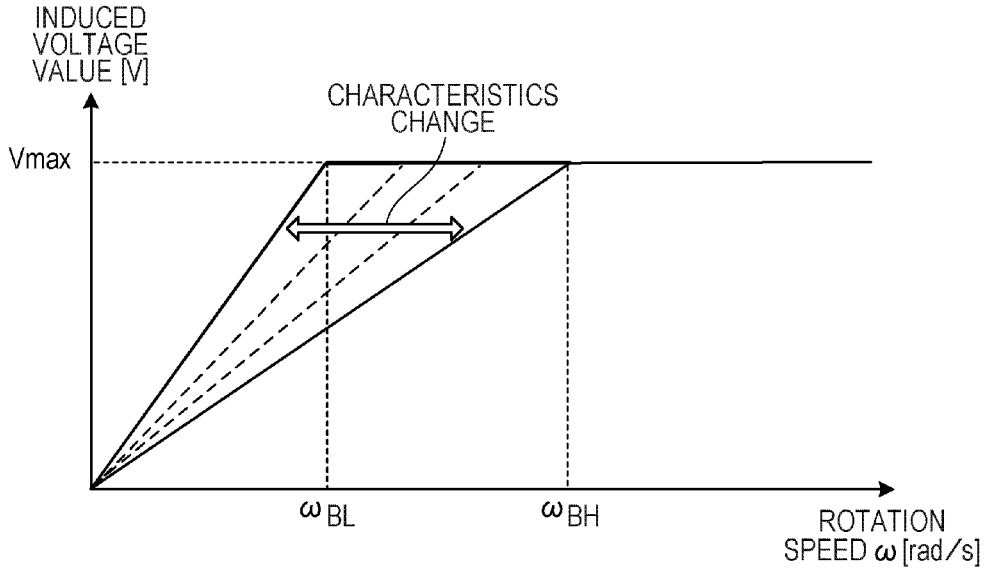

INDUCED VOLTAGE VALUE [V]
CHARACTERISTICS CHANGE
Vmax
ωBL
ωBH
ROTATION SPEED ω [rad/s]

FIG. 13

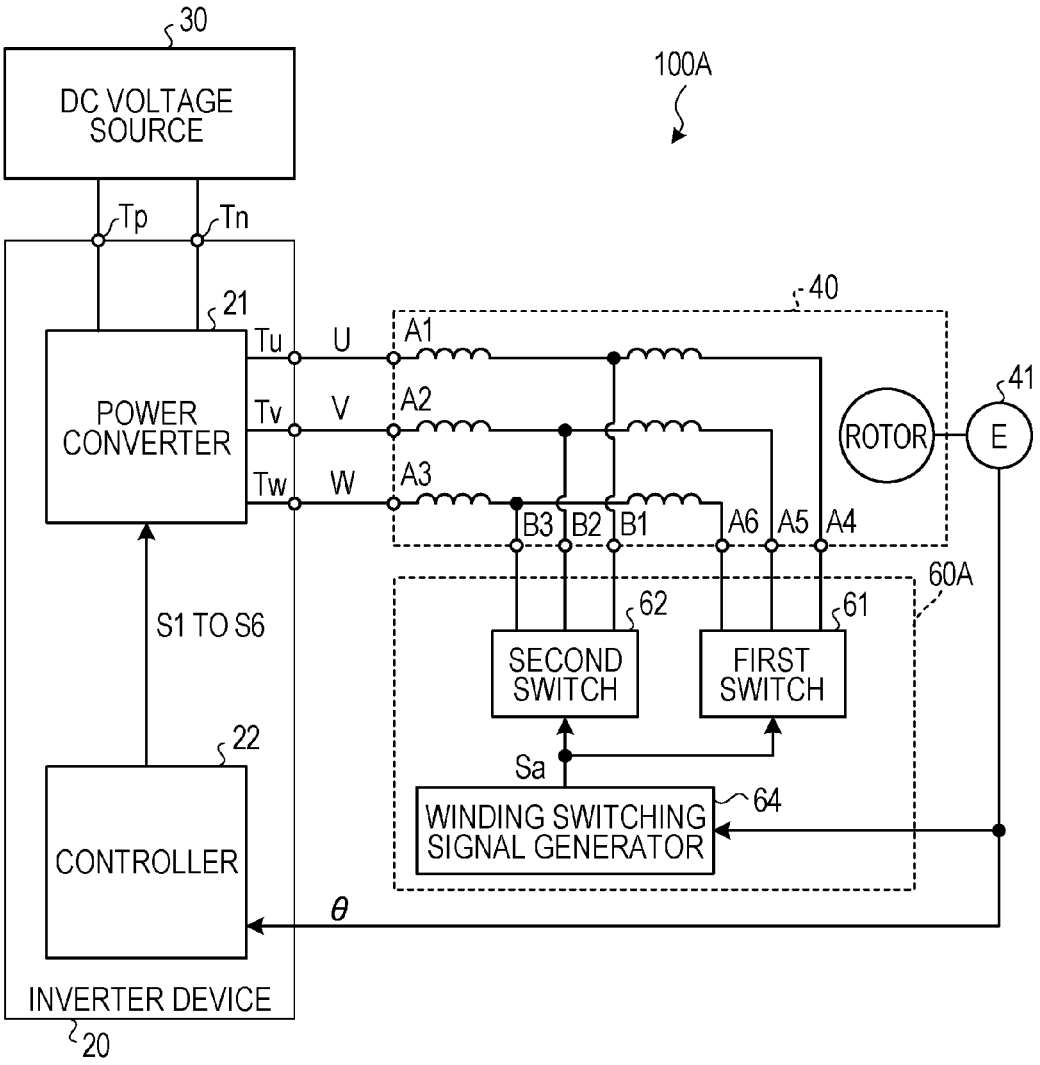

30
DC VOLTAGE SOURCE
100A
Tp
Tn
21
40
POWER CONVERTER
Tu
Tv
Tw
U
V
W
A1
A2
A3
ROTOR
41
E
B3
B2
B1
A6
A5
A4
60A
62
61
SECOND SWITCH
FIRST SWITCH
S1 TO S6
22
Sa
64
WINDING SWITCHING SIGNAL GENERATOR
CONTROLLER
θ
INVERTER DEVICE
20

FIG. 14

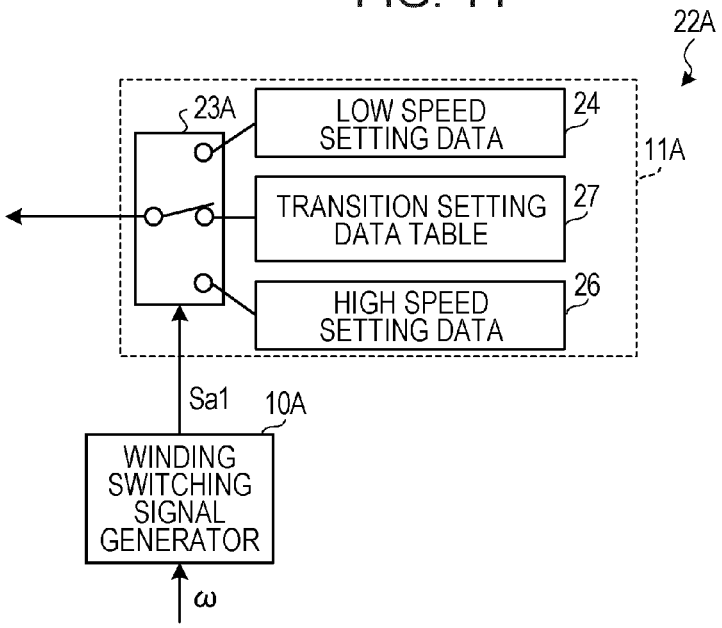

22A
23A
LOW SPEED SETTING DATA
24
11A
TRANSITION SETTING DATA TABLE
27
HIGH SPEED SETTING DATA
26
Sa1
10A
WINDING SWITCHING SIGNAL GENERATOR
ω

FIG. 15

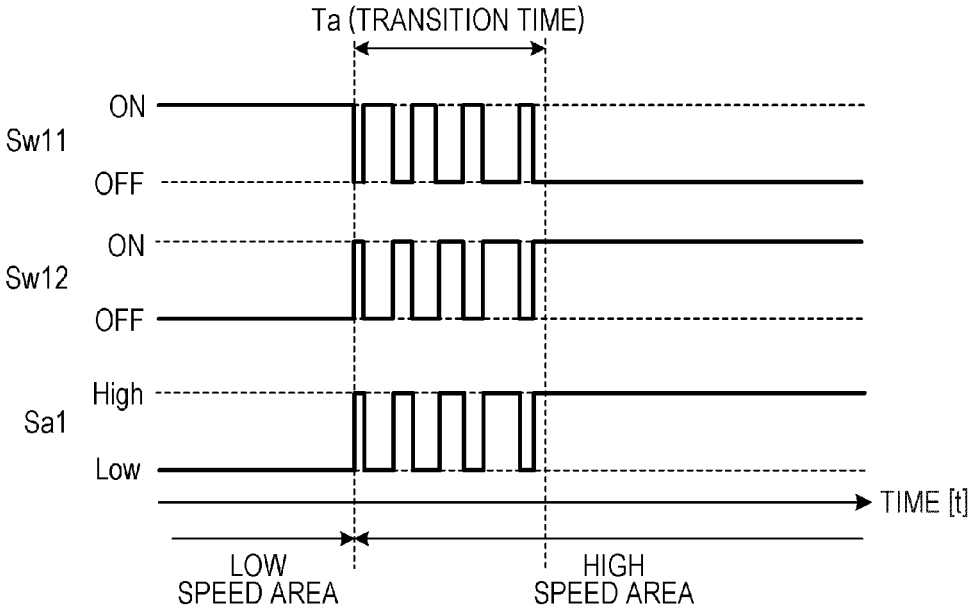

Ta (TRANSITION TIME)
ON
Sw11
OFF
ON
Sw12
OFF
High
Sa1
Low
TIME [t]
LOW SPEED AREA
HIGH SPEED AREA

FIG. 16

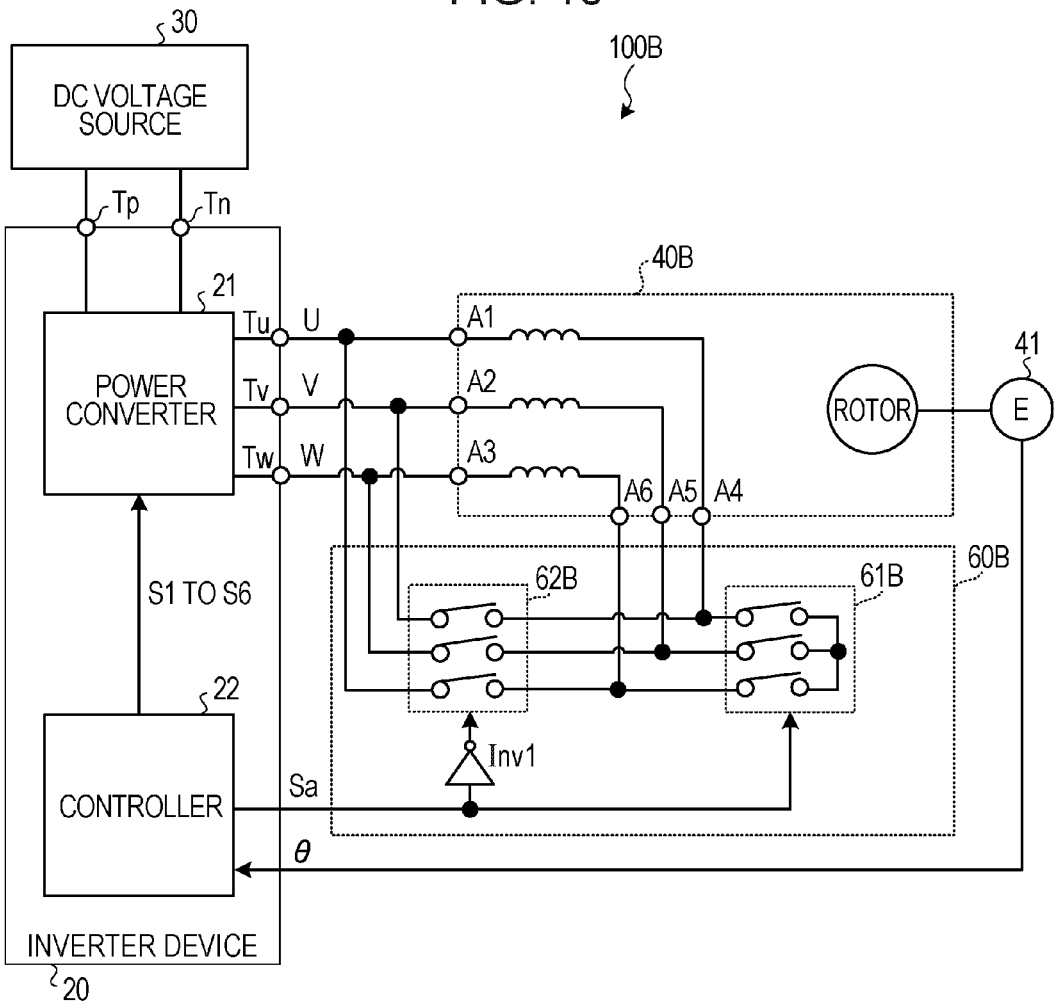

30
DC VOLTAGE SOURCE
100B
Tp
Tn
40B
21
POWER CONVERTER
Tu
U
Tv
V
Tw
W
A1
A2
A3
A6
A5
A4
41
ROTOR
E
60B
62B
61B
S1 TO S6
22
CONTROLLER
Inv1
Sa
θ
INVERTER DEVICE
20

FIG. 17

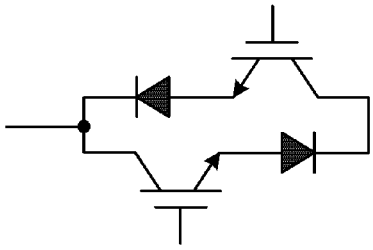


FIG. 18

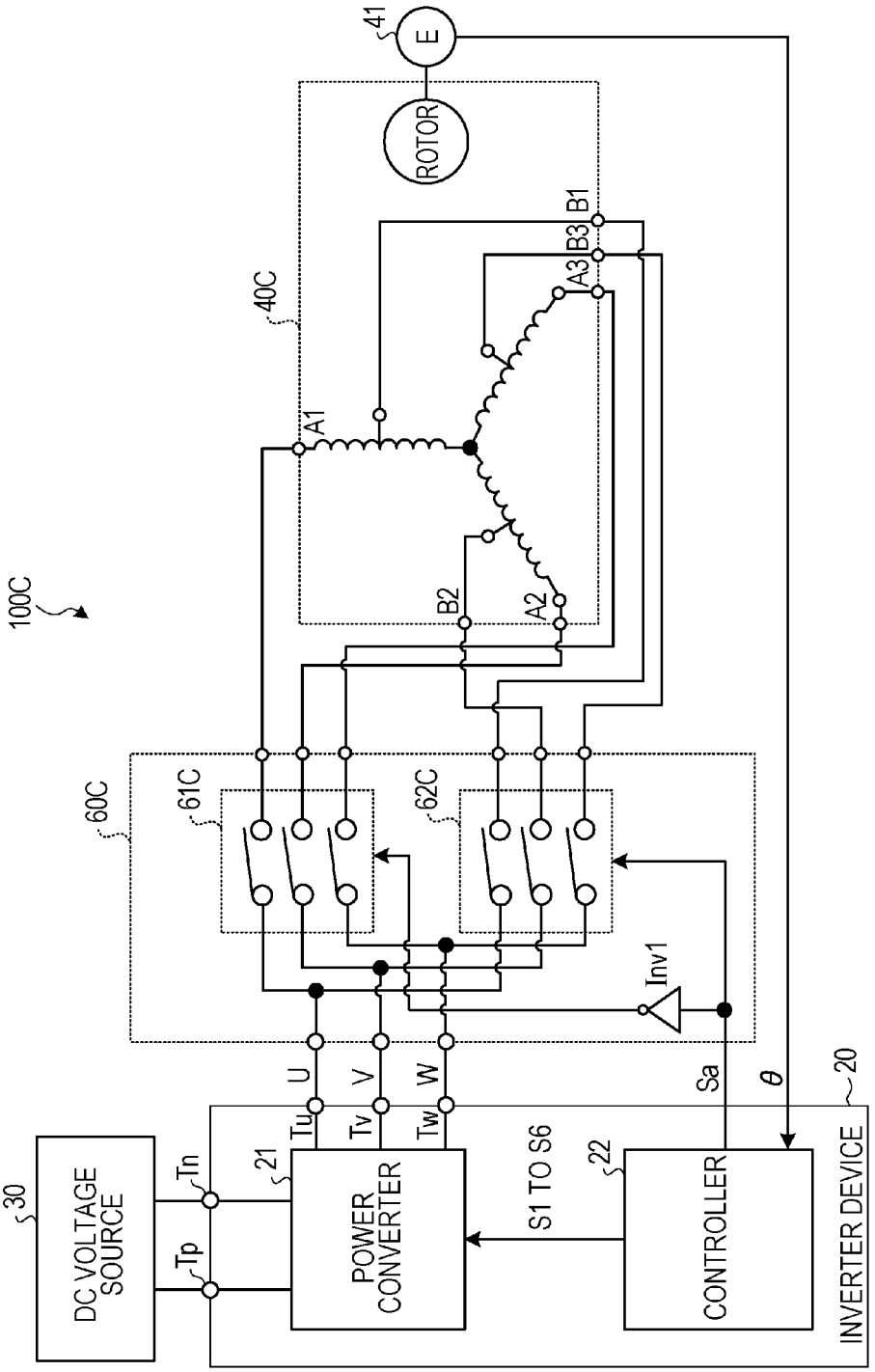

100C
41
E
ROTOR
40C
B1
B3
A3
A1
B2
A2
60C
61C
62C
Inv1
U
V
W
Tu
Tv
Tw
Sa
θ
20
30
DC VOLTAGE SOURCE
Tn
Tp
21
POWER CONVERTER
S1 TO S6
22
CONTROLLER
INVERTER DEVICE

FIG. 19

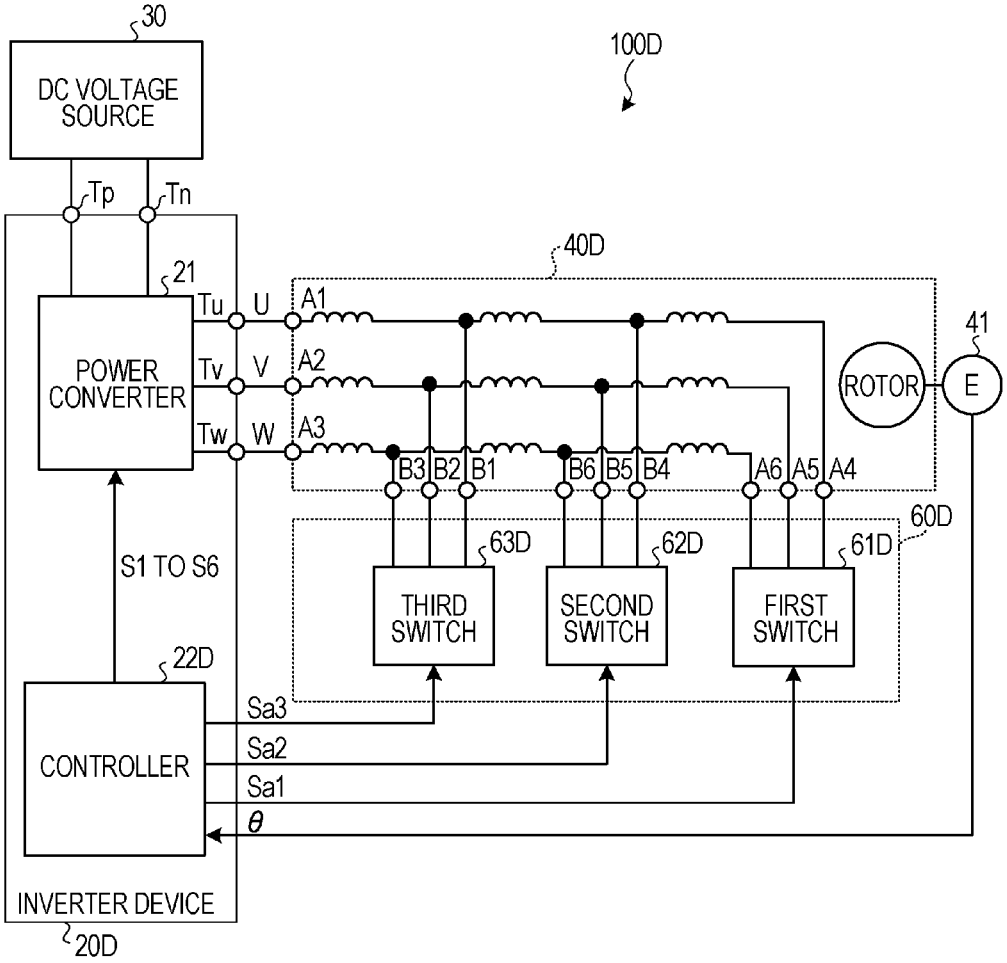

30
DC VOLTAGE SOURCE
100D
Tp
Tn
40D
21
POWER CONVERTER
Tu
Tv
Tw
U
V
W
A1
A2
A3
41
ROTOR
E
B3
B2
B1
B6
B5
B4
A6
A5
A4
60D
63D
62D
61D
THIRD SWITCH
SECOND SWITCH
FIRST SWITCH
S1 TO S6
22D
CONTROLLER
Sa3
Sa2
Sa1
θ
INVERTER DEVICE
20D

FIG. 20

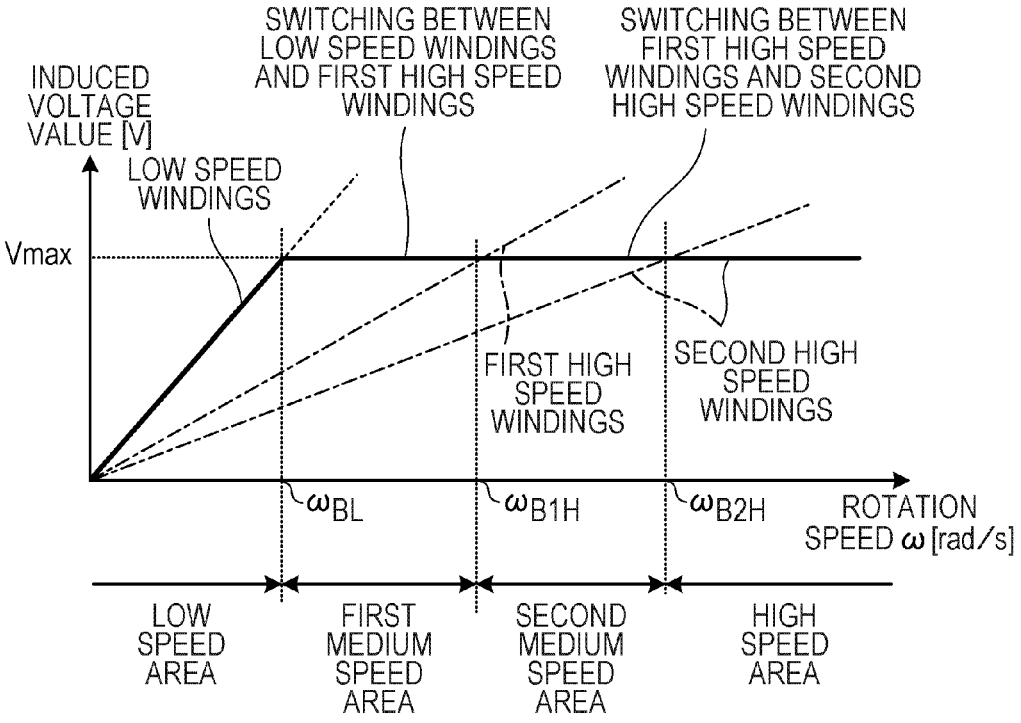
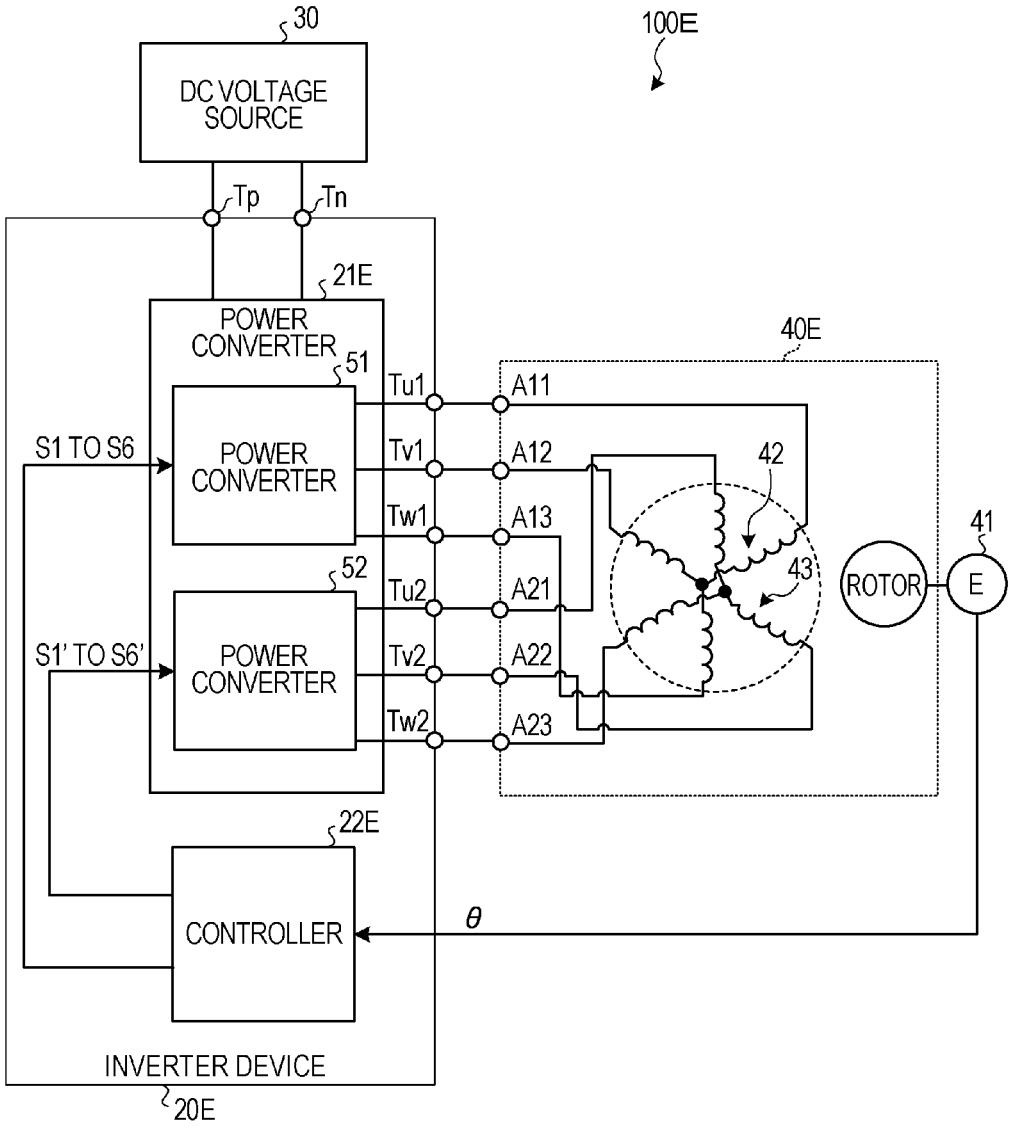

SWITCHING BETWEEN LOW SPEED WINDINGS AND FIRST HIGH SPEED WINDINGS
SWITCHING BETWEEN FIRST HIGH SPEED WINDINGS AND SECOND HIGH SPEED WINDINGS
INDUCED VOLTAGE VALUE [V]
LOW SPEED WINDINGS
Vmax
FIRST HIGH SPEED WINDINGS
SECOND HIGH SPEED WINDINGS
ωBL
ωB1H
ωB2H
ROTATION SPEED ω [rad/s]
LOW SPEED AREA
FIRST MEDIUM SPEED AREA
SECOND MEDIUM SPEED AREA
HIGH SPEED AREA

FIG. 21


30
DC VOLTAGE SOURCE
100E
Tp
Tn
21E
POWER CONVERTER
51
Tu1
Tv1
Tw1
S1 TO S6
POWER CONVERTER
52
Tu2
Tv2
Tw2
S1' TO S6'
POWER CONVERTER
40E
A11
A12
A13
A21
A22
A23
42
43
ROTOR
41
E
22E
CONTROLLER
θ
INVERTER DEVICE
20E

INVERTER DEVICE AND MOTOR DRIVE SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

The present disclosure contains subject matter related to that disclosed in Japanese Priority Patent Application JP 2013-018808 filed in the Japan Patent Office on Feb. 1, 2013, the entire contents of which are hereby incorporated by reference.

BACKGROUND

1. Field of the Invention

The embodiments disclosed herein relate to an inverter device and a motor drive system.

2. Description of the Related Art

There has been available a winding switching method enabling a wide-area operation from a low speed area to a high speed area by switching the armature windings of an alternating-current (AC) motor to switch the electric characteristics of the AC motor.

In this winding switching method, to reduce a shock caused by switching of the windings, measures are taken, such as prohibiting switching of the windings in a circumstance where the number of rotations of the AC motor is rapidly changing (see Japanese Unexamined Patent Application Publication No. 06-225588).

However, when such measures are taken, the efficiency is low in the case where the speed is consecutively increasing from low speed to high speed, for example, and a sufficient torque is not obtained. To this end, the present applicant has proposed in Japanese Unexamined Patent Application Publication No. 2010-22165 an inverter device capable of reducing a shock caused by switching of the windings even during acceleration or deceleration.

The inverter device described in Japanese Unexamined Patent Application Publication No. 2010-22165 calculates a d-axis current command correction value, which is a correction value of a d-axis current command, when a voltage command exceeds a maximum voltage value that can be output to an AC motor, and performs field weakening control that corrects the d-axis current command by using the calculated d-axis current command correction value. In this field weakening control, the inverter device described in Japanese Unexamined Patent-Application Publication No. 2010-22165 preliminarily calculates a d-axis current command correction value prior to switching of the windings, and, at a winding switching timing, corrects the d-axis current command by using the pre-calculated d-axis current command correction value.

Accordingly, a delay in calculating a d-axis current command correction value, which is one of the causes of a shock caused by switching of the windings, can be removed, and smooth winding switching becomes possible even during acceleration or deceleration.

However, because the inverter device described in Japanese Unexamined Patent Application Publication No. 2010-22165 preliminarily calculates a d-axis current command correction value prior to switching of the windings and corrects a d-axis current value by using the d-axis current command correction value at a winding switching timing, the processing is complicated.

SUMMARY

According to an aspect of the disclosure, there is provided an inverter device including a power supply unit and a switch controller. The power supply unit supplies alternating-current (AC) power to an AC motor whose electric characteristics in response to a rotation speed are switchable between low speed characteristics and high speed characteristics. The switch controller switches the electric characteristics of the AC motor. The switch controller executes switching control that alternately switches the electric characteristics of the AC motor between the low speed characteristics and the high speed characteristics on the basis of the rotation speed of the AC motor.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram illustrating a motor drive system according to a first embodiment;

FIG. **2** is a diagram illustrating an example of the waveform of a voltage output from an inverter device to an AC motor in a medium speed operation;

FIG. **3** is a circuit diagram illustrating the configuration of a power converter and a winding switch unit illustrated in FIG. **1**;

FIG. **4** is a diagram illustrating a specific configuration of a controller of the inverter device illustrated in FIG. **1**;

FIG. **5** is a diagram illustrating an example of a specific configuration of a current controller;

FIG. **6** is a diagram illustrating an example of a specific configuration of a constant output controller;

FIG. **7** is a diagram illustrating the relationship among the rotation speed, induced voltage value, and winding state of the AC motor;

FIG. **8** is a diagram illustrating an example of the waveform of an output voltage of the inverter device in the case where the winding state of the AC motor is a switching status between low speed windings and high speed windings;

FIG. **9** is a diagram illustrating the relationship between the rotation speed and the ON ratio of a winding switching signal;

FIG. **10** is a diagram illustrating an example of the waveform of the winding switching signal;

FIG. **11** is a diagram illustrating the relationship among the ON ratio of switching elements and the time ratio of the low speed windings and the high speed windings in the case where the AC motor is accelerated;

FIG. **12** is a diagram illustrating the relationship between the rotation speed and induced voltage value of the AC motor in the motor drive system;

FIG. **13** is a diagram illustrating another configuration of the motor drive system according to the first embodiment;

FIG. **14** is a diagram illustrating the configuration of a controller of the inverter device according to a second embodiment;

FIG. **15** is a diagram illustrating the state of the switching elements and the state of the winding switching signal in the case where the AC motor is accelerated from a low speed area to a high speed area;

FIG. **16** is a diagram illustrating the configuration of a drive system according to a third embodiment;

FIG. **17** is a diagram illustrating an example of each switch configuring a first switch and a second switch illustrated in FIG. **16**;

FIG. **18** is a diagram illustrating the configuration of a drive system according to a fourth embodiment;

FIG. **19** is a diagram illustrating the configuration of a drive system according to a fifth embodiment;

FIG. **20** is a diagram illustrating the relationship among the rotation speed, induced voltage value, and winding state of the AC motor; and

FIG. **21** is a diagram illustrating the configuration of a drive system according to a sixth embodiment.

DESCRIPTION OF THE EMBODIMENTS

Hereinafter, embodiments of an inverter device and a motor drive system (hereinafter simply referred to as a "drive system") according to the present disclosure will be described in detail with reference to the accompanying drawings. As an example in which the electric characteristics of an AC motor in response to the rotation speed are switched, an example in which the winding state of the AC motor is switched will be described in first to fifth embodiments, and an example in which the number of poles of the AC motor is switched will be described in a sixth embodiment. However, the present disclosure is not limited by these embodiments.

First Embodiment

Firstly, a drive system according to the first embodiment will be described. FIG. **1** is a diagram illustrating the drive system according to the first embodiment.

As illustrated in FIG. **1**, a drive system **100** according to the first embodiment includes an AC motor **40**, an inverter device **20**, a direct-current (DC) voltage source **30**, a position detector **41**, and a winding switch **60**.

The inverter device **20** is a power inverter including a power converter **21** (an example of a power supply unit) and a controller **22**. The power converter **21** is controlled by the controller **22**. The inverter device **20** includes input terminals Tp and Tn and output terminals Tu, Tv, and Tw. The inverter device **20** converts DC power, supplied from the DC voltage source **30** via the input terminals Tp and Tn, into three-phase AC power by using the power converter **21**, and outputs the three-phase AC power from the output terminals Tu, Tv, and Tw.

The DC voltage source **30** includes an AC power source and a rectifier circuit and supplies DC power to the inverter device **20**. The DC voltage source **30** may be a DC power source without having a rectifier circuit, such as a battery.

The AC motor **40** is a three-phase AC motor including a set of three-phase armature windings of U-phase, V-phase, and W-phase and is driven by a voltage (hereinafter referred to as an output terminal voltage) output from the output terminals Tu, Tv, and Tw of the inverter device **20**. The AC motor **40** is provided with, for the individual phases, connection terminals A1 to A6 for extracting two ends of the armature windings and connection terminals B1 to B3 for extracting the midpoints of the armature windings.

The connection terminals A1 to A3 are provided at one ends of the armature windings of the individual phases and are connected respectively to the output terminals Tu, Tv, and Tw of the inverter device **20**. In addition, the winding switch **60** is connected to the connection terminals A4 to A6, provided at termination ends of the armature windings of the individual phases, and the connection terminals B1 to B3, provided at the midpoints of the armature windings of the individual phases.

The position detector **41** is connected to an output shaft of the AC motor **40** and detects the phase θ of a rotor of the AC motor **40** (hereinafter referred to as a rotor phase θ). The position detector **41** is, for example, an encoder or a resolver.

The winding switch **60** switches the connection of the armature windings of the individual phases. The winding switch **60** includes a first switch **61** connected to the connection terminals A4 to A6 of the AC motor **40** and a second switch **62** connected to the connection terminals B1 to B3 of the AC motor **40**. The winding switch **60** is controlled by the controller **22** of the inverter device **20**. The winding switch **60** and the controller **22** are an example of a switch controller.

The controller **22** causes the first switch **61** to operate, thereby short-circuiting the termination ends of the armature windings of the AC motor **40** and switching the winding state of the AC motor **40**. Accordingly, the impedance of the AC motor **40** is maximized. This winding state is called the low speed windings (exemplary low speed characteristics). The higher the rotation speed becomes, the greater the induced voltage of the AC motor **40** becomes and the easier the output terminal voltage becomes saturated. Thus, field weakening control is started at a relatively low speed. The output terminal voltage is a voltage including the induced voltage of the AC motor **40** and a voltage drop caused by the primary impedance of the AC motor **40**.

Meanwhile, the controller **22** causes the second switch **62** to operate, thereby short-circuiting the midpoints of the armature windings of the AC motor **40** and switching the winding state of the AC motor **40**. Accordingly, the impedance of the AC motor **40** decreases. This winding state is called the high speed windings (exemplary high speed characteristics). When the winding state of the AC motor **40** is the high speed windings, the induced voltage decreases by decreasing the impedance.

The controller **22** causes the first switch **61** to operate in a low speed operation and causes the second switch **62** to operate in a high speed operation, thereby switching the winding state.

Further, between a low speed operation based on the low speed windings and a high speed operation based on the high speed windings, the controller **22** executes switching control that alternately switches the winding state of the AC motor **40** between the low speed windings and the high speed windings.

FIG. **2** is a diagram illustrating an example of the waveform of a voltage output from the inverter device **20** to the AC motor **40** in an operation based on the low speed windings and the high speed windings (hereinafter referred to as a medium speed operation). As illustrated in FIG. **2**, switching control is executed at a frequency higher than the output frequency of the inverter device **20** in a medium speed operation.

In switching control, the controller **22** adjusts the ratio between a time in which the winding state is switched to the low speed windings and a time in which the winding state is switched to the high speed windings in accordance with the speed of the AC motor **40**. Accordingly, a medium voltage between a voltage in the case of the low speed windings and a voltage in the case of the high speed windings can be obtained. Therefore, compared with the case, as has been done previously, in which the operation is switched between a low speed operation based on the low speed windings and a high speed operation based on the high speed windings, even during acceleration or deceleration, sudden fluctuations of winding characteristics can be suppressed, and effects caused by switching of the windings can be suppressed.

Accordingly, an increase in the induced voltage can be suppressed without relying on field weakening control. A speed area where the efficiency is high can be enlarged.

Hereinafter, specific configurations of the inverter device **20** and the winding switch **60** according to the first embodiment will be described. Firstly, the specific configuration of the winding switch **60** will be described, and then the specific configuration of the inverter device **20** will be described.

Exemplary Configuration of Winding Switch **60**

FIG. **3** is a circuit diagram illustrating the configuration of the power converter **21** and the winding switch **60**. As has been described earlier, the winding switch **60** includes the first switch **61** connected to the connection terminals A4 to A6 of the AC motor **40**, the second switch **62** connected to the connection terminals B1 to B3 of the AC motor **40**, and a logical NOT circuit Inv1. The winding switch **60** switches the winding characteristics of the AC motor **40** by short-circuiting the termination ends or the midpoints of the armature windings of the AC motor **40** by using the first switch **61** and the second switch **62**.

As illustrated in FIG. **3**, the first switch **61** includes a three-phase diode bridge DB1, a switching element Sw11, a resistor element R1, a capacitor element C1, and diodes D11 and D12. AC input terminals Tu1, Tv1, and Tw1 of the three-phase diode bridge DB1 are respectively connected to the connection terminals A4 to A6 of the AC motor **40**.

The switching element Sw11 is connected to a DC output side of the three-phase diode bridge DB1 and connects or opens the DC outputs of the three-phase diode bridge DB1. The switching element Sw11 is a self-arc-extinguishing semiconductor switch such as a bipolar transistor or an insulated gate bipolar transistor (IGBT).

The resistor element R1 and the capacitor element C1 are connected via the diodes D11 and d12 to the DC output side of the three-phase diode bridge DB1. The resistor element R1 and the capacitor element C1 effectively absorb a surge voltage generated by energy discharged at the time of switching of the windings.

The second switch **62** is a circuit that is the same as or similar to the first switch **61** and includes a three-phase diode bridge DB2, a switching element Sw12, a resistor element R2, a capacitor element C2, and diodes D13 and D14. AC input terminals Tu2, Tv2, and Tw2 of the three-phase diode bridge DB2 are respectively connected to the connection terminals B1 to B3 of the AC motor **40**. The resistor element R2 and the capacitor element C2 may be shared with the resistor element R1 and the capacitor element C1 of the first switch **61**.

The first switch **61** and the second switch **62** are controlled by a winding switching signal Sa, described later, output from the controller **22**. When the controller **22** outputs the winding switching signal Sa at a low level, the logical NOT circuit Inv1 inputs the signal at a high level to the switching element Sw11, and the switching element Sw11 enters an ON state. In addition, the winding switching signal Sa at a low level causes the switching element Sw12 to enter an OFF state. Accordingly, the connection terminals B1 to B3 of the AC motor **40** are short-circuited, and the winding state of the AC motor **40** becomes the low speed windings.

Meanwhile, when the controller **22** outputs the winding switching signal Sa at a high level, the logical NOT circuit Inv1 inputs the signal at a low level to the switching element Sw11, and the switching element Sw11 enters an OFF state. In addition, the winding switching signal Sa at a high level causes the switching element Sw12 to enter an ON state. Accordingly, the connection terminals A4 to A6 of the AC motor **40** are short-circuited, and the winding state of the AC motor **40** becomes the high speed windings.

It is simply necessary for the first switch **61** to cause the winding state of the AC motor **40** to become the low speed windings, and for the second switch **62** to cause the winding state of the AC motor **40** to become the high speed windings. The configurations of the first switch **61** and the second switch **62** are not limited to those illustrated in FIG. **3**.

Configuration of Inverter Device **20**

Next, the configuration of the inverter device **20** according to the first embodiment will be described using FIGS. **3** and **4**. FIG. **4** is a diagram illustrating a specific configuration of the controller **22** of the inverter device **20** according to the first embodiment.

As illustrated in FIG. **4**, the controller **22** of the inverter device **20** includes a torque command generator **1**, a current command calculator **2**, a current controller **3**, a phase-width-modulation (PWM) signal generator **4**, a current detector **5**, and an analog-to-digital (A/D) converter **6**. The controller **22** further includes a voltage detector **7**, a constant output controller **8**, a speed calculator **9**, a winding switching signal generator **10**, and a constant switch **11**. The winding switching signal generator **10**, the constant switch **11**, and the winding switch **60** are an example of a switch controller.

The torque command generator **1** generates a torque command T_ref, which is a target value of the amount of torque generated by the AC motor **40**, and outputs the torque command T_ref to the current command calculator **2** and the constant output controller **8**. Alternatively, the torque command T_ref may be input from an external controller of the inverter device **20**, which is not illustrated.

The current command calculator **2** generates a d-axis current command Id_ref and a q-axis current command Iq_ref on the basis of the torque command T_ref from the torque command generator **1** and a motor constant and a control parameter from the constant switch **11**.

The current command calculator **2** calculates a d-axis current command Id_ref1 on the basis of, for example, a torque-current conversion factor K, and a current phase β with respect to the q-axis direction, which is a directional vector orthogonal to the d-axis direction. The current command calculator **2** adds the d-axis current command Id_ref1 to a constant output amount Id_refc from the constant output controller **8** to obtain a d-axis current command Id_ref, and outputs the d-axis current command Id_ref to the current controller **3**.

In addition, the current command calculator **2** calculates a q-axis current command Iq_ref on the basis of, for example, a d-axis inductance value Ld of the armature windings and a q-axis inductance value Lq of the armature windings, and outputs the calculated q-axis current command Iq_ref to the current controller **3**.

The current controller **3** generates voltage commands Vd_ref and Vq_ref by controlling current in accordance with the d-axis current command Id_ref and the q-axis current command Iq_ref from the current command calculator **2** to flow through the AC motor **40**, and converts the voltage commands Vd_ref and Vq_ref into voltage commands Vu_ref, Vv_ref, and Vw_ref of the individual phases. The current controller **3** outputs the voltage commands Vd_ref and Vq_ref to the constant output controller **8**, and outputs the voltage commands Vu_ref, Vv_ref, and Vw_ref to the PWM signal generator **4**.

FIG. **5** is a diagram illustrating an example of the specific configuration of the current controller **3**. As illustrated in FIG. **5**, the current controller **3** includes coordinate converters **70** and **77**, subtractors **71** and **72**, a d-axis current controller **73**, and a q-axis current controller **74**.

The coordinate converter **70** converts detected current values Iu_fb and Iv_fb from the A/D converter **6** into current feedback values Id_fb and Iq_fb on the basis of the rotor phase θ. The subtractor **71** subtracts the d-axis current feedback value Id_fb from the d-axis current command Id_ref and outputs the subtraction result to the d-axis current controller **73**. In addition, the subtractor **72** subtracts the q-axis current

feedback value Iq_fb from the q-axis current command Iq_ref and outputs the subtraction result to the q-axis current controller **74**.

The d-axis current controller **73** controls the subtraction result obtained by the subtractor **71** to be 0, and the q-axis current controller **74** controls the subtraction result obtained by the subtractor **72** to be 0. The d-axis current controller **73** and the q-axis current controller **74** perform, for example, proportional-plus-integral (PI) control and output voltage commands Vd_ref and Vq_ref, respectively.

The coordinate converter **77** converts the voltage commands Vd_ref and Vq_ref into voltage commands Vu_ref, Vv_ref, and Vw_ref of the U-phase, V-phase, and W-phase on the basis of the rotor phase θ, and outputs the voltage commands Vu_ref, Vv_ref, and Vw_ref to the PWM signal generator **4**.

Referring back to FIG. **4**, the description of the controller **22** will be continuously given. The PWM signal generator **4** generates PWM signals S1 to S6 on the basis of the results of comparison between an internally generated carrier wave signal Vt with the voltage commands Vu_ref, Vv_ref, and Vw_ref from the current controller **3**, and outputs the PWM signals S1 to S6 to the power converter **21**. The power converter **21** includes, for example, as illustrated in FIG. **3**, switching elements Sw1 to Sw6 connected to a three-phase bridge, and diodes D1 to D6 connected in anti-parallel with the switching elements Sw1 to Sw6, respectively.

The controller **22** controls the switching elements Sw1 to Sw6 to be turned ON/OFF in response to the PWM signals S1 to S6, thereby outputting a voltage with a certain frequency and a voltage value from the power converter **21** to the AC motor **40**.

The current detector **5** illustrated in FIG. **4** detects current flowing through the windings of the AC motor **40**. Current values Iu_fb and Iv_fb detected by the current detector **5** are output to the A/D converter **6**.

The A/D converter **6** converts the current values Iu_fb and Iv_fb detected by the current detector **5** into digital signals. The detected current values Iu_fb and Iv_fb converted by the A/D converter **6** into digital signals are output to the current controller **3**.

The voltage detector **7** detects the voltage value of the DC voltage source **30**, specifically, a DC voltage value Vbat across the input terminals Tp and Tn of the inverter device **20** to which the DC voltage source **30** is connected, and outputs the detected DC voltage value Vbat to the constant output controller **8**.

In the case where an amplitude value Vfb of a voltage command obtained from the voltage commands Vd_ref and Vq_ref (hereinafter referred to as a voltage amplitude value Vfb) reaches an outputtable maximum voltage value Vmax based on the DC voltage value Vbat of the voltage detector **7**, the constant output controller **8** calculates a constant output amount Id_refc on the basis of the voltage commands Vd_ref and Vq_ref and the maximum voltage value Vmax. The calculated constant output amount Id_refc is used for field weakening control. In this manner, constant output control is performed on the basis of the voltage amplitude value Vfb and the maximum voltage value Vmax.

FIG. **6** is a diagram illustrating an example of the specific configuration of the constant output controller **8**. As illustrated in FIG. **6**, the constant output controller **8** includes an amplitude calculator **81**, a subtractor **82**, a PI controller **83**, a limiter **84**, and a filter **85**.

The amplitude calculator **81** calculates a voltage amplitude value Vfb from the voltage commands Vd_ref and Vq_ref, and outputs the calculated voltage amplitude value Vfb as a voltage feedback value Vfb to the subtractor **82**.

The subtractor **82** subtracts the voltage feedback value Vfb from the maximum voltage value Vmax, and outputs the subtraction result to the PI controller **83**. The maximum voltage value Vmax is determined on the basis of the DC voltage value Vbat from the voltage detector **7** or by multiplying the DC voltage value Vbat with a coefficient, which is not illustrated.

The PI controller **83** performs PI control of the subtraction result obtained by the subtractor **82**, and operates so that the voltage feedback value Vfb does not exceed the maximum voltage value Vmax. To this end, the limiter **84** limits the output of the PI controller **83** to be 0 when the output is a positive value and limits the output to a certain value when the output is a negative value, and outputs the limited value to the filter **85**. The output value of the limiter **84** is output as a constant output value Id_refc via the filter **85**. Note that the filter **85** is provided as occasion calls.

Referring back to FIG. **4**, the description of the controller **22** will be continuously given. The speed calculator **9** calculates the rotation speed ω of the AC motor **40** on the basis of the rotor phase θ from the position detector **41**. The calculated rotation speed ω is output to the winding switching signal generator **10**.

The winding switching signal generator **10** causes winding switching to be executed by outputting a winding switching signal Sa to the winding switch **60**. Specifically, the winding switching signal generator **10** generates a winding switching signal Sa in accordance with the rotation speed co from the speed calculator **9**, and outputs the winding switching signal Sa to the winding switch **60** and the constant switch **11**.

The winding switching signal Sa is a signal synchronized with the carrier wave signal Vt from the PWM signal generator **4**, and is generated on the basis of a signal obtained by dividing the frequency of the carrier wave signal Vt. The frequency of the carrier wave signal Vt is, for example, 10 k Hz, and the frequency of a signal obtained by dividing the frequency of the carrier wave signal Vt is, for example, 1 k Hz. The winding switching processing performed by the controller **22** will be described later using FIGS. **7** to **13**.

The constant switch **11** holds low speed and high speed motor constants and control parameter data (hereinafter referred to as setting data). In response to the winding switching signal Sa from the winding switching signal generator **10**, the constant switch **11** outputs selected setting data to the current command calculator **2**, and switches to the motor constant and control parameter that match the winding state of the AC motor **40**.

The setting data held by the constant switch **11** includes, for example, the torque-current conversion coefficient K, the current phase β, the armature winding inductance values Ld and Lq, an armature flux linkage φ, and an armature winding resistance value R.

The constant switch **11** includes a switch **23**, low speed setting data **24**, a medium speed setting data table **25**, and high speed setting data **26**. Setting data corresponding to the time ratio of the winding switching signal Sa is set in the medium speed setting data table **25**.

The constant switch **11** switches the switch **23** in response to the winding switching signal Sa, and obtains and outputs setting data in response to the winding switching signal Sa from the low speed setting data **24**, the medium speed setting data table **25**, and the high speed setting data **26**. Instead of the medium speed setting data table **25**, the constant switch **11** may output setting data in response to the winding switching

signal Sa by performing an arithmetic operation of calculating setting data in response to the winding switching signal Sa.

Winding Switching Processing Performed by Controller **22**

Next, the winding switching processing performed by the controller **22** will be specifically described. The controller **22** sets the winding state of the AC motor **40** to one of the low speed windings, a switching state between the low speed windings and the high speed windings, and the high speed windings in accordance with the rotation speed ω from the speed calculator **9**.

FIG. **7** is a diagram illustrating the relationship among the rotation speed ω, induced voltage value, and winding state of the AC motor **40**. As illustrated in FIG. **7**, in the case of a low speed area in which the rotation speed ω is less than or equal to a first reference rotation speed ω_{BL}, the winding switching signal generator **10** outputs the winding switching signal Sa at a low level to the winding switch **60**. Accordingly, the winding state of the AC motor **40** becomes the low speed windings. Note that the first reference rotation speed ω_{BL} is, for example, a rotation speed ω at which the induced voltage value of the AC motor **40** in the case where the winding state is the low speed windings becomes the maximum voltage value Vmax.

In addition, in the case of a high speed area where the rotation speed ω is greater than or equal to a second reference rotation speed ω_{BH}, the winding switching signal generator **10** outputs the winding switching signal Sa at a high level to the winding switch **60**. Accordingly, the winding state of the AC motor **40** becomes the state of the high speed windings. Note that the second reference rotation speed ω_{BH} is, for example, a rotation speed ω at which the induced voltage value of the AC motor **40** in the case where the winding state is the high speed windings becomes the maximum voltage value Vmax.

Meanwhile, in the case of a medium speed area in which the rotation speed ω is greater than the first reference rotation speed ω_{BL} and less than the second reference rotation speed ω_{BH}, the winding switching signal generator **10** outputs the winding switching signal Sa at a certain frequency (such as 1 kHz) that becomes a high level at a time ratio in accordance with the rotation speed ω to the winding switch **60**. Accordingly, the winding state of the AC motor **40** is alternately switched between the low speed windings and the high speed windings.

In the case where the rotation speed ω is greater than the first reference rotation speed ω_{BL} and less than the second reference rotation speed ω_{BH}, if the winding state of the AC motor **40** is the state of the low speed windings, the induced voltage value of the AC motor **40** reaches the maximum voltage value Vmax, and thus, the induced voltage value of the AC motor **40** is maintained at the maximum voltage value Vmax by field weakening control. Meanwhile, if the winding state of the AC motor **40** is the high speed windings, the induced voltage value of the AC motor **40** does not reach the maximum voltage value Vmax.

To this end, in the case where the rotation speed ω is greater than the first reference rotation speed ω_{BL} and less than the second reference rotation speed ω_{BH}, the winding state of the AC motor **40** is alternately switched between the low speed windings and the high speed windings, and the induced voltage value of the AC motor **40** is maintained to be less than or equal to the maximum voltage value Vmax without relying on field weakening control.

Accordingly, as illustrated in FIG. **8**, a voltage (hereinafter referred to as a medium speed winding voltage) between a voltage based on the low speed windings (hereinafter referred to as a low speed winding voltage) and a voltage based on the high speed windings (hereinafter referred to as a high speed winding voltage) can be generated. FIG. **8** is a diagram illustrating an example of the waveform of an output voltage of the inverter device **20** in the case where the winding state of the AC motor **40** is a switching state between the low speed windings and the high speed windings.

The medium speed winding voltage in a medium speed operation is generated by a voltage based on the low speed winding and a voltage based on the high speed windings, as illustrated in FIG. **8**. Thus, the medium speed winding voltage can be arbitrarily adjusted between the low speed winding voltage and the high speed winding voltage by adjusting a time in which the winding state of the AC motor **40** is the low speed windings (hereinafter referred to as a low speed winding time) and a time in which the winding state of the AC motor **40** is the high speed windings (hereinafter referred to as a high speed winding time) in a medium speed operation. Accordingly, in an area where the shaft output of the AC motor **40** becomes constant output by using a known method, if the inverter control according to the present disclosure is performed, a highly efficient area can be enlarged by alternately switching between constant torque control with the low speed windings and constant torque control with the high speed windings.

FIG. **9** is a diagram illustrating the relationship between the rotation speed ω and the ON ratio Tr of the winding switching signal Sa. The ON ratio Tr is the ratio between a low level and a high level. In the case where the low speed winding time is 100%, the ON ratio Tr is 100%; in the case where the high speed winding time is 100%, the ON ratio Tr is 0%. As illustrated in FIG. **9**, in the case where the rotation speed ω is less than or equal to the first reference rotation speed ω_{BL}, the ON ratio Tr is 100%; in the case where the rotation speed ω is greater than or equal to the second reference rotation speed ω_{BH}, the ON ratio Tr is 0%.

In the case where the rotation speed ω is greater than the first reference rotation speed ω_{BL} and is less than the second reference rotation speed ω_{BH}, the ON ratio Tr is set to approach 0% as the rotation speed ω becomes faster. FIG. **10** is a diagram illustrating an example of the waveform of the winding switching signal Sa. As illustrated in FIG. **10**, for the winding switching signal Sa, an ON period T_L in which the winding switching signal Sa is at a low level and an OFF period T_H in which the winding switching signal Sa is at a high level are set in every cycle Tc. The ON ratio Tr of the winding switching signal Sa is represented by T_L/T_C.

The winding switching signal Sa is input to the constant switch **11**, as described earlier. Accordingly, setting data in response to the winding switching signal Sa is output from the constant switch **11**. Specifically, in the case where the ON ratio Tr of the winding switching signal Sa is 0%, the constant switch **11** switches the switch **23** to the low speed setting data **24**, and obtains and outputs setting data from the low speed setting data **24**. Meanwhile, in the case where the ON ratio Tr of the winding switching signal Sa is 100%, the constant switch **11** switches the switch **23** to the high speed setting data **26**, and obtains and outputs setting data from the high speed setting data **26**.

In addition, in the case where the time ratio of the winding switching signal Sa exceeds 0% and falls below 100%, the constant switch **11** switches the switch **23** to the medium speed setting data table **25**. In the medium speed setting data table **25**, setting data in accordance with the ON ratio Tr of the winding switching signal Sa is set. The constant switch **11** obtains and outputs setting data in accordance with the ON

ratio Tr of the winding switching signal Sa from the medium speed setting data table **25**. Accordingly, setting data can be consecutively switched.

In the example illustrated in FIG. **4**, setting data in accordance with the ON ratio Tr of the winding switching signal Sa is set in the table. Alternatively, instead of the arithmetic operation table, setting data in accordance with the ON ratio Tr of the winding switching signal Sa may be output by an arithmetic operation that calculates setting data in accordance with the ON ratio Tr of the winding switching signal Sa.

In this manner, the constant switch **11** outputs setting data in response to the winding switching signal Sa, and the setting data is input to the current command calculator **2**. Accordingly, the current command calculator **2** switches to the motor constant and control parameter that match the winding state of the AC motor **40**.

FIG. **11** is a diagram illustrating the relationship among the ON ratio of the switching elements Sw11 and Sw12 and the time ratio of the low speed windings and the high speed windings in the case where the AC motor **40** is accelerated. As illustrated in FIG. **11**, in the case where the AC motor **40** is accelerated/decelerated, the time ratio of the low speed windings and the time ratio of the high speed windings consecutively change between 0% and 100%, and also setting data output from the constant switch **11** consecutively changes.

Therefore, in the drive system **100** according to the first embodiment, the AC motor **40** can be operated in a manner equivalent to the case in which an AC motor whose characteristics change as illustrated in FIG. **12** is virtually operated. FIG. **12** is a diagram illustrating the relationship between the rotation speed ω and induced voltage value of the AC motor **40** in the drive system **100**.

Accordingly, the drive system **100** according to the first embodiment can further enlarge a highly efficient area by alternately switching the winding state between the low speed windings and the high speed windings at the time ratio in accordance with the rotation speed ω. In addition, effects caused by switching the windings can be lessened, compared with the case in which the winding state of the AC motor **40** is suddenly switched.

In addition, as has been described above, the winding switching signal generator **10** generates the winding switching signal Sa as a signal synchronized with the carrier wave signal Vt from the PWM signal generator **4**. Accordingly, the effect of a switching noise caused by switching the windings can be further suppressed.

Alternatively, the winding switching signal Sa may be a signal out of synchronization with the carrier wave signal Vt from the PWM signal generator **4**, as illustrated in FIG. **13**. FIG. **13** is a diagram illustrating another configuration of the drive system according to the first embodiment. A drive system **100**A illustrated in FIG. **13** includes, besides the winding switching signal generator **10** of the inverter device **20**, a winding switching signal generator **64** of a winding switch **60**A. Accordingly, in the case where the inverter device **20** and the winding switch **60**A are at distant places, the drive system **100**A can dispense with the work of routing cables, and independent control can be performed.

In addition, in the case where the winding switching signal Sa is a signal synchronized with the carrier wave signal Vt, if the windings are switched, the detection timing of the detected current values Iu_fb and Iv_fb detected by the current detector **5** may be concurrent with the winding switching timing of the AC motor **40**. Immediately after the windings of the AC motor **40** are switched, if the winding state of the AC motor **40** changes, the accuracy of the detected current values Iu_fb and Iv_fb become deteriorated.

To this end, the controller **22** does not use detected current values Iu_fb and Iv_fb detected by the current detector **5** at the winding switching timing of the AC motor **40**, but uses detected current values Iu_fb and Iv_fb detected at one prior timing to generate the voltage commands Vd_ref and Vq_ref. Accordingly, the accuracy deterioration of the voltage output from the power converter **21** can be suppressed.

Second Embodiment

Next, a drive system according to the second embodiment will be described. In the drive system **100** according to the first embodiment, the AC motor **40** is operated at a medium speed by performing switching control between the low speed windings and the high speed windings. In the drive system according to the second embodiment, instead of a medium speed operation, the AC motor **40** is operated in a transition operation. In the following description, points different from the drive system **100** according to the first embodiment are mainly discussed, and elements with the same or similar functions as those in the first embodiment are given the same reference numerals, descriptions of which are omitted.

FIG. **14** is a diagram illustrating the configuration of a controller **22**A of the inverter device **20** according to the second embodiment. In FIG. **14**, only a winding switching signal generator **10**A and a constant switch **11**A are illustrated, and other configurations are omitted.

In the case where the rotation speed ω is less than or equal to a reference rotation speed ω_{BR}, the winding switching signal generator **10**A outputs a winding switching signal Sa1 at a low level to the winding switch **60**. In the case where the rotation speed ω is greater than or equal to the reference rotation speed ω_{BR}, the winding switching signal generator **10**A outputs the winding switching signal Sa1 at a high level to the winding switch **60**.

Meanwhile, in the case where the rotation speed ω accelerates and becomes greater than the reference rotation speed ω_{BR} or decelerates and becomes less than the reference rotation speed ω_{BR}, the winding switching signal generator **10**A outputs the winding switching signal Sa1 whose time ratio consecutively changes between 0% and 100% in accordance with time to the winding switch **60**. Accordingly, while the winding state of the AC motor **40** is alternately switched between the low speed windings and the high speed windings, transition from a low speed operation to a high speed operation and transition from a high speed operation to a low speed operation are performed. As with the case of the winding switching signal Sa according to the first embodiment, the winding switching signal Sa1 is a pulse signal at a certain frequency (such as 1 kHz).

FIG. **15** is a diagram illustrating the state of the switching elements Sw11 and Sw12 and the state of the winding switching signal Sa1 in the case where the AC motor **40** is accelerated from a low speed area to a high speed area. As illustrated in FIG. **15**, in the case where the AC motor **40** is accelerated from a low speed area to a high speed area, in the low speed area, the winding switching signal Sa1 is at a low level, the switching element Sw11 is switched ON, the switching element Sw12 is switched OFF, and the winding state of the AC motor **40** becomes the low speed windings.

Thereafter, when the rotation speed ω exceeds the reference rotation speed ω_{BR} and reaches a high speed area, for a certain time Ta, the time ratio of the winding switching signal Sa1 consecutively changes from 0% to 100% in accordance with time, and the switching elements Sw11 and Sw12 are switched ON/OFF in accordance with the time ratio of the winding switching signal Sa1. After the certain time Ta

elapses, the winding switching signal Sa1 becomes a high level (time ratio is 100%), the switching element Sw11 is switched OFF, the switching element Sw12 is switched ON, and the winding state of the AC motor **40** becomes the high speed windings.

Accordingly, in transition from a state in which one type of the low speed windings and the high speed windings is connected to the power converter **21** to a state in which the other type of windings is connected to the power converter **21**, the winding switching signal generator **10**A executes switching control that alternately switches the winding state between the low speed windings and the high speed windings while shortening the time in which the one type of windings is connected to the power converter **21**.

The constant switch **11**A includes a switch **23**A, the low speed setting data **24**, the high speed setting data **26**, and a transition setting data table **27**. In the case where the winding switching signal Sa1 is at a low level, the constant switch **11**A outputs the low speed setting data **24** from the switch **23**A. In the case where the winding switching signal Sa1 is at a high level, the constant switch **11**A outputs the high speed setting data **26** from the switch **23**A.

Further, in the case where the winding switching signal Sa1 is changing between a low level and a high level, the switch **23**A changes setting data set in the transition setting data table **27** and outputs this setting data for a certain period. In the transition setting data table **27**, setting data in accordance with the ON ratio of the winding switching signal Sa1 is set. Accordingly, the constant switch **11**A can change and output the setting data for a certain period.

Accordingly, in the drive system according to the second embodiment, in transition from a low speed area to a high speed area or in transition from a high speed area to a low speed area, transition between a low speed operation and a high speed operation is performed while the winding state of the AC motor **40** is alternately switched between the low speed windings and the high speed windings. Thus, effects caused by switching the windings can be lessened, compared with the case in which the winding state of the AC motor **40** is suddenly switched.

As with the case of the first embodiment, the winding switching signal Sa1 may be a signal out of synchronization with the carrier wave signal Vt from the PWM signal generator **4**. Besides the winding switching signal generator **10**A of the inverter device **20**, the winding switching signal generator **64** may be provided in the winding switch **60**. In addition, the controller **22**A may not use detected current values Iu_fb and Iv_fb detected by the current detector **5** at the winding switching timing of the AC motor **40**, but may use detected current values Iu_fb and Iv_fb detected at one prior timing to generate the voltage commands Vd_ref and Vq_ref.

Third Embodiment

In the drive system **100** according to the first embodiment, the connection state of the armature windings is changed by changing the number of windings of a star (Y) connection. In a drive system according to the third embodiment, the connection state of the armature windings is changed by switching between the star connection and a delta (Δ) connection. In the following description, points different from the drive system **100** according to the first embodiment are mainly discussed, and elements with the same or similar functions as those in the first embodiment are given the same reference numerals, descriptions of which are omitted.

FIG. **16** is a diagram illustrating the configuration of a drive system **100**B according to the third embodiment. As illustrated in FIG. **16**, an AC motor **40**B is provided with connection terminals A1 to A6 for extracting two ends of the armature windings for the individual phases. A winding switch **60**B is connected to these connection terminals A1 to A6.

The winding switch **60**B includes a first switch **61**B connected to the connection terminals A4 to A6 of the AC motor **40**B, a second switch **62**B connected to the connection terminals A1 to A3 of the AC motor **40**B, and the logical NOT circuit Inv1. Switches constituting the first switch **61**B and the second switch **62**B are constituted by, for example, semiconductor elements.

FIG. **17** is a diagram illustrating an example of each of the switches constituting the first switch **61**B and the second switch **62**B. In the example illustrated in FIG. **17**, each switch is configured by an anti-parallel connection of series circuits each including a diode and a switching element. Alternatively, this configuration may be different as long as the configuration uses a semiconductor element that can perform high-speed connection/opening for AC voltage current.

The controller **22** of the inverter device **20** causes the first switch **61**B to operate, thereby short-circuiting the termination ends of the armature windings of the AC motor **40**B and switching the winding state of the AC motor **40**B to a star connection, which corresponds to the low speed windings. Meanwhile, the controller **22** of the inverter device **20** causes the second switch **62**B to operate, thereby connecting one ends of the armature windings to the other ends of the armature windings of different phases and switching the winding state of the AC motor **40**B to a delta connection, which corresponds to the high speed windings.

The controller **22** causes the first switch **61**B to operate in a low speed operation and causes the second switch **62**B to operate in a high speed operation, thereby switching the winding state. Further, as with the case of the first and second embodiments, the controller **22** executes switching control that alternately switches the winding state between the low speed windings and the high speed windings at a time ratio in accordance with the speed of the AC motor **40**B in a speed area between a low speed operation based on the low speed windings and a high speed operation based on the high speed windings.

Accordingly, since the drive system **100**B according to the third embodiment alternately switches the connection state between the star connection and the delta connection at a time ratio in accordance with the speed of the AC motor **40**B, a highly efficient area can be enlarged, as with the cases of the drive system **100** according to the first embodiment.

Instead of switching the connection state between the star connection and the delta connection, the winding state of the armature windings may be switched by changing the number of windings of the delta Δ connection. As with the case of the second embodiment, the controller **22**A may be provided instead of the controller **22**. In this case, in transition from a low speed area to a high speed area or in transition from a high speed area to a low speed area, the controller **22**A may perform transition between a low speed operation and a high speed operation while alternately switching the winding state of the AC motor **40**B between the star connection and the delta connection.

Fourth Embodiment

In the drive system **100** according to the first embodiment, the winding state of the armature windings is switched by changing the position of a neutral point of the armature windings. In a drive system according to the fourth embodiment, the winding state of the armature windings is switched with-

out changing the position of the neutral point. In the following description, points different from the drive system **100** according to the first embodiment are mainly discussed, and elements with the same or similar functions as those in the first embodiment are given the same reference numerals, descriptions of which are omitted.

FIG. **18** is a diagram illustrating the configuration of a drive system **100**C according to the fourth embodiment. As illustrated in FIG. **18**, an AC motor **40**C is provided with, for the individual phases, connection terminals A1 to A3 for extracting one ends of the armature windings and connection terminals B1 to B3 for extracting the midpoints of the armature windings. A winding switch **60**C is connected to the connection terminals A1 to A3 and B1 to B3.

The winding switch **60**C includes a first switch **61**C connected to the connection terminals A1 to A3 of the AC motor **40**C, a second switch **62**C connected to the connection terminals B1 to B3 of the AC motor **40**C, and the logical NOT circuit Inv1. Switches constituting the first switch **61**C and the second switch **62**C are constituted by semiconductor elements so that connection/opening for AC voltage current can be performed at a high speed (for example, see FIG. **17**).

The controller **22** of the inverter device **20** causes the first switch **61**C to operate, thereby connecting the connection terminals A1 to A3 of the AC motor **40**C to the power converter **21** and switching the winding state of the AC motor **40**C. Accordingly, the impedance of the AC motor **40**C is maximized. This winding state is called the low speed windings.

Meanwhile, the controller **22** of the inverter device **20** causes the second switch **62**C to operate, thereby connecting the connection terminals B1 to B3 of the AC motor **40**C to the power converter **21** and switching the winding state of the AC motor **40**C. Accordingly, the impedance of the AC motor **40**C decreases. This winding state is called the high speed windings.

The controller **22** causes the first switch **61**C to operate in a low speed operation and causes the second switch **62**C to operate in a high speed operation, thereby switching the winding state. Further, the controller **22** executes switching control that alternately switches the winding state between the low speed windings and the high speed windings at a time ratio in accordance with the speed of the AC motor **40**C in a speed area between a low speed operation based on the low speed windings and a high speed operation based on the high speed windings.

Accordingly, since the drive system **100**C according to the fourth embodiment alternately switches the winding state of the star connection between the low speed windings and the high speed windings, as with the case of the drive system **100** according to the first embodiment, a highly efficient area can be enlarged, as with the cases of the drive system **100** according to the first embodiment.

As with the case of the second embodiment, the controller **22**A may be provided instead of the controller **22**. In this case, in transition from a low speed area to a high speed area or in transition from a high speed area to a low speed area, the controller **22**A may perform transition between a low speed operation and a high speed operation while alternately switching the winding state between the low speed windings and the high speed windings of the AC motor **40**C.

Fifth Embodiment

In the drive systems **100** and **100**A to **100**C according to the above-described embodiments, switching between the two winding states is performed. In a drive system according to the fifth embodiment, switching among three winding states is performed. In the following description, an example in which the number of windings of the star connection is switched among three levels will be described by way of example. It is only necessary to switch among three or more winding states. For example, the number of windings of the delta connection may be switched among three or more levels. In addition, in the following description, points different from the drive system **100** according to the first embodiment are mainly discussed, and elements with the same or similar functions as those in the first embodiment are given the same reference numerals, descriptions of which are omitted.

FIG. **19** is a diagram illustrating the configuration of a drive system **100**D according to the fifth embodiment. As illustrated in FIG. **19**, in an AC motor **40**D, a winding switch **60**D is connected to connection terminals A1 to A6 for extracting two ends of the armature windings and connection terminals B1 to B6 provided at middle portions of the armature windings for the individual phases.

The winding switch **60**D includes a first switch **61**D connected to the connection terminals A4 to A6 of the AC motor **40**D, a second switch **62**D connected to the connection terminals B4 to B6 of the AC motor **40**D, and a third switch **63**D connected to the connection terminals B1 to B3 of the AC motor **40**D. The first to third switches **61**D, **62**D, and **63**D have the same or similar configuration as the first switch **61** and the second switch **62** (see FIG. **3**). Switches constituting the first to third switches **61**D, **62**D, and **63**D are constituted by semiconductor elements so that connection/opening for AC voltage current can be performed at a high speed (for example, see FIG. **17**).

FIG. **20** is a diagram illustrating the relationship between the rotation speed ω and winding state of the AC motor **40**D. As illustrated in FIG. **20**, a controller **22**D of the inverter device **20**D switches the winding state in response to the rotation speed ω among a low speed area, a first medium speed area, a second medium speed area, and a high speed area. This switching is performed by winding switching signals Sa1 to Sa3.

Specifically, in the case of the low speed area in which the rotation speed ω is less than or equal to a first reference rotation speed ω_{BL}, the controller **22**D outputs the winding switching signal Sa1 at a high level and the winding switching signals Sa2 and Sa3 at a low level. Accordingly, the connection terminals A4 to A6 of the AC motor **40**D are connected to one another to form a neutral point, and the impedance of the AC motor **40**D is maximized.

In the case of the high speed area in which the rotation speed ω is greater than or equal to a third reference rotation speed ω_{B2H}, the controller **22**D outputs the winding switching signal Sa3 at a high level and the winding switching signals Sa1 and Sa2 at a low level. Accordingly, the connection terminals B1 to B3 of the AC motor **40**D are connected to one another to form a neutral point, and the impedance of the AC motor **40**D is minimized.

Meanwhile, in the case of the first medium speed area in which the rotation speed ω is greater than the first reference rotation speed ω_{BL} and less than a second reference rotation speed ω_{B1H}, the controller **22**D outputs the winding switching signal Sa3 at a low level and the winding switching signals Sa1 and Sa2 which alternately become a high level. Accordingly, the controller **22**D executes switching control that alternately switches the winding state between the low speed windings and the first high speed windings at a time ratio in accordance with the speed of the AC motor **40**D. Note that the first high speed windings correspond to the winding state of the AC motor **40**D in the case where the connection terminals

B4 to B6 of the AC motor **40**D are connected to one another by the second switch **62**D to form a neutral point.

In addition, in the case of the second medium speed area in which the rotation speed ω is greater than or equal to the second reference rotation speed ω_{B1H} and less than the third reference rotation speed ω_{B2H}, the controller **22**D outputs the winding switching signal Sa1 at a low level and the winding switching signals Sa2 and Sa3 which alternately become a high level. Accordingly, the controller **22**D executes switching control that alternately switches the winding state between the first high speed windings and second the high speed windings at a time ratio in accordance with the speed of the AC motor **40**D. Note that the second high speed windings correspond to the winding state of the AC motor **40**D in the case where the connection terminals B1 to B3 of the AC motor **40**D are connected to one another by the third switch **63**D to form a neutral point.

As has been described above, the drive system **100**D according to the fifth embodiment can switch the winding state of the AC motor **40**D to four states, namely, a state of only the low speed windings, a switching state between the low speed windings and the first high speed windings, a switching state between the first high speed windings and the second high speed windings, and a state of only the high speed windings. Accordingly, a highly efficient area can be further enlarged, compared with the drive systems **100**, **100**A, and the like according to the above-described embodiments.

As with the case of the drive system **100**A of the second embodiment, in the case of transition of the winding state of the AC motor **40**B between the low speed windings and the first high speed windings and in the case of transition between the first high speed windings and the second high speed windings, transition of the winding state of the AC motor **40**B may be performed while alternately switching the winding state by performing switching control.

Sixth Embodiment

In the drive systems **100** and **100**A to **100**D according to the above-described embodiments, the electric characteristics of the AC motor are switched by switching the winding state of the AC motor. In a drive system according to the sixth embodiment, the electric characteristics of an AC motor are switched by switching the number of poles of the AC motor. In addition, in the following description, points different from the drive system **100** according to the first embodiment are mainly discussed, and elements with the same or similar functions as those in the first embodiment are given the same reference numerals, descriptions of which are omitted.

FIG. **21** is a diagram illustrating the configuration of a drive system **100**E according to the sixth embodiment. As illustrated in FIG. **21**, the drive system **100**E includes an inverter device **20**E and an AC motor **40**E. The inverter device **20**E includes a power converter **21**E and a controller **22**E. The power converter **21**E includes two power converters **51** and **52**. The power converters **51** and **52** have the same or similar configuration as the power converter **21** (see FIG. **3**) and are controlled by PWM signals S1 to S6 and S1' to S6' output from the controller **22**E.

The AC motor **40**E is a double-winding AC motor with two sets of three-phase armature windings **42** and **43**. The two sets of three-phase armature windings **42** and **43** are sets of windings with different specifications. In the AC motor **40**E, the power converter **51** is connected to connection terminals A11 to A13 provided at one ends of one set of three-phase armature windings **42**, and the power converter **52** is connected to connection terminals A21 to A23 provided at one ends of the other set of three-phase armature windings **43**.

The controller **22**E of the inverter device **20**E can cause the AC motor **40**E to operate as a 2n-pole (such as four-pole) motor by supplying homopolar currents from the two power converters **51** and **52** to the two sets of three-phase armature windings **42** and **43**. In addition, the controller **22**E can cause the AC motor **40**E to operate as an n-pole (such as two-pole) motor by supplying antipolar currents from the two power converters **51** and **52** to the two sets of three-phase armature windings **42** and **43**.

As has been described above, the drive system **100**E according to the sixth embodiment drives the two sets of three-phase armature windings **42** and **43** with different specifications included in one AC motor **40**E by the two power converters **51** and **52**, and switches the number of poles of the motor by switching a combination of current vectors. Because the technology of switching the number of poles of a motor is publicly known technology as described in IEEE Transactions on Industry Applications, Vol. 32d No. 4, July/August, 1996, pp. 938-944, for example, a description thereof is omitted here.

In the case of a low speed operation in which the rotation speed ω is less than or equal to the first reference rotation speed ω_{BL1}, the controller **22**E supplies homopolar currents from the two power converters **51** and **52** to the two sets of three-phase armature windings **42** and **43**. In this case, because the AC motor **40**E operates as a 2n-pole (an example of the number of poles for low speed) motor, the electric characteristics of the AC motor **40**E become low speed characteristics in which the number of poles is great.

In addition, in the case of a high speed operation in which the rotation speed ω is greater than or equal to the second reference rotation speed ω_{BH1} ($>\omega_{BL1}$), the controller **22**E supplies antipolar currents from the two power converters **51** and **52** to the two sets of three-phase armature windings **42** and **43**. In this case, because the AC motor **40**E operates as an n-pole (an example of the number of poles for high speed) motor, the electric characteristics of the AC motor **40**E become high speed characteristics in which the number of poles is small.

Meanwhile, in the case of a medium speed operation in which the rotation speed ω is greater than the first reference rotation speed ω_{BL1} and less than the second reference rotation speed ω_{BH1}, the controller **22**E switches the winding state between a state in which the controller **22**E supplies homopolar currents to the two sets of three-phase armature windings **42** and **43** and a state in which the controller **22**E supplies antipolar currents to the two sets of three-phase armature windings **42** and **43** at a time ratio in accordance with the speed of the AC motor **40**E.

Accordingly, the drive system **100**E according to the sixth embodiment executes switching control that alternately switches the number of poles of the AC motor **40**E between 2n-poles and n-poles of the AC motor **40**E at a time ratio in accordance with the speed of the AC motor **40**E. Therefore, even during acceleration or deceleration, fluctuations of the electric characteristics of the AC motor **40**E can be suppressed, and effects caused by switching of the electric characteristics of the AC motor **40**E can be suppressed. In addition, a highly efficient area can be enlarged.

As with the case of the second embodiment, in transition from a low speed area to a high speed area or in transition from a high speed area to a low speed area, transition between a low speed operation and a high speed operation may be performed while alternately switching the number of poles

between the number of poles for low speed and the number of poles for high speed of the AC motor **40**E.

As has been described above, in the drive systems **100** and **100**A to **100**E according to the above-described embodiments, effects caused by switching of the electric characteristics of the AC motors **40** and **40**B to **40**E can be suppressed, and a highly efficient area can be enlarged by executing switching control that alternately switches the electric characteristics of the AC motors **40** and **40**B to **40**E at a time ratio in accordance with the speed of the AC motors **40** and **40**B to **40**E.

In the drive systems **100** and **100**A according to the above-described embodiments, for example, the AC motor **40** may be a double-winding AC motor in which the low speed windings and the high speed windings are separate sets of windings.

Although the inverter device **20** is described as a voltage-source inverter in the above-described embodiments, the inverter device **20** may be a current-source inverter.

Although switching control in which the rotation speed of the AC motors **40** and **40**B to **40**E is detected and the electric characteristics of the AC motors **40** and **40**B to **40**E are alternately switched is performed in the above-described embodiments, it is only necessary to accordingly perform switching control in accordance with the rotation speed ω of the AC motors **40** and **40**B to **40**E. Therefore, the case in which switching control is performed by detecting the output voltage or output current of the inverter device **20** and the case of V/f constant control in which switching control is performed at a command frequency for the AC motor **40** are also included in control in accordance with speed.

It should be understood by those skilled in the art that various modifications, combinations, sub-combinations and alterations may occur depending on design requirements and other factors insofar as they are within the scope of the appended claims or the equivalents thereof.

What is claimed is:

1. An inverter device comprising:

a power supply unit that supplies alternating-current (AC) power to an AC motor whose electric characteristics in response to a rotation speed are switchable between low speed characteristics and high speed characteristics; and

a switch controller that switches the electric characteristics of the AC motor,

wherein the switch controller executes switching control that alternately switches the electric characteristics of the AC motor between the low speed characteristics and the high speed characteristics on the basis of the rotation speed of the AC motor in a case where the rotation speed of the AC motor is greater than a first reference rotation speed and less than a second reference rotation speed which is greater than the first reference rotation speed,

wherein the electric characteristics of the AC motor are switchable by switching a winding state between a low speed winding and a high speed winding, and

wherein the switch controller executes the switching control by alternately switching the winding state of the AC motor between the low speed winding and the high speed winding.

2. The inverter device according to claim **1**, wherein the switch controller executes the switching control at a time ratio in accordance with the rotation speed of the AC motor.

3. The inverter device according to claim **1**, wherein, in the case of transition of the electric characteristics of the AC motor from one characteristic state of the low speed characteristics and the high speed characteristics to the other characteristic state, the switch controller executes switching control that alternately switches the electric characteristics of the AC motor between the one characteristic state and the other characteristic state while shortening a time of the one characteristic state.

4. The inverter device according to claim **1**,

wherein the electric characteristics of the AC motor are switchable by switching the number of poles, and

wherein the switch controller executes switching control that alternately switches the number of poles of the AC motor between the number of poles for low speed and the number of poles for high speed on the basis of the rotation speed of the AC motor.

5. The inverter device according to claim **1**,

wherein the power supply unit includes

a power converter including a switching element, and

a phase-width modulation (PWM) signal generator that outputs a PWM signal on the basis of a comparison between a voltage command and a carrier wave and controls the switching element, and

wherein the switch controller executes the switching control in synchronization with the carrier wave.

6. The inverter device according to claim **5**, further comprising a command generator that generates the voltage command from a torque command on the basis of setting data including a motor constant and a control parameter,

wherein the switch controller obtains the setting data in accordance with the switching control by using a table or an arithmetic operation, and outputs the setting data to the command generator.

7. The inverter device according to claim **1**,

wherein the power supply unit includes

a power converter including a switching element, and

a phase-width modulation (PWM) signal generator that outputs a PWM signal on the basis of a comparison between a voltage command and a carrier wave and controls the switching element, and

wherein the switch controller executes the switching control out of synchronization with the carrier wave.

8. The inverter device according to claim **1**, wherein the switch controller executes the switching control at a frequency higher than an output frequency of the power supply unit.

9. The inverter device according to claim **1**, further comprising:

a constant switch connected to the switch controller so as to select and output a setting data in response to a winding switching signal from the switch controller to switch the winding state of the AC motor,

wherein the constant switch selects and outputs the setting data among a low speed setting data for the low speed characteristics, a high speed setting data for the high speed characteristics, and a medium speed setting data for the switching control in response to the winding switching signal, and

wherein the AC power is made based on the setting data.

10. A motor drive system comprising:

an alternating-current (AC) motor whose electric characteristics in response to a rotation speed are switchable between low speed characteristics and high speed characteristics;

a power supply unit that supplies AC power to the AC motor; and

a switch controller that switches the electric characteristics of the AC motor,

wherein the switch controller executes switching control that alternately switches the electric characteristics of the AC motor between the low speed characteristics and

the high speed characteristics on the basis of the rotation speed of the AC motor in a case where the rotation speed of the AC motor is greater than a first reference rotation speed and less than a second reference rotation speed which is greater than the first reference rotation speed,

wherein the electric characteristics of the AC motor are switchable by switching a winding state between a low speed winding and a high speed winding, and

wherein the switch controller executes the switching control by alternately switching the winding state of the AC motor between the low speed winding and the high speed winding.

11. The motor drive system according to claim **10**, wherein the switch controller executes the switching control at a frequency higher than an output frequency of the power supply unit.

12. The motor drive system according to claim **10**, further comprising:

a constant switch connected to the switch controller so as to select and output a setting data in response to a winding switching signal from the switch controller to switch the winding state of the AC motor,

wherein the constant switch selects and outputs the setting data among a low speed setting data for the low speed characteristics, a high speed setting data for the high speed characteristics, and a medium speed setting data for the switching control in response to the winding switching signal, and

wherein the AC power is made based on the setting data.

13. An inverter device comprising:

power supply means for supplying alternating-current (AC) power to an AC motor whose electric characteristics in response to a rotation speed are switchable between low speed characteristics and high speed characteristics; and

switch control means for switching the electric characteristics of the AC motor,

wherein the switch control means executes switching control that alternately switches the electric characteristics of the AC motor between the low speed characteristics and the high speed characteristics on the basis of the rotation speed of the AC motor in a case where the rotation speed of the AC motor is greater than a first reference rotation speed and less than a second reference rotation speed which is greater than the first reference rotation speed,

wherein the electric characteristics of the AC motor are switchable by switching a winding state between a low speed winding and a high speed winding, and

wherein the switch control means executes the switching control by alternately switching the winding state of the AC motor between the low speed winding and the high speed winding.

14. The inverter device according to claim **13**, wherein the switch control means executes the switching control at a time ratio in accordance with the rotation speed of the AC motor.

15. The inverter device according to claim **13**, wherein, in the case of transition of the electric characteristics of the AC motor from one characteristic state of the low speed characteristics and the high speed characteristics to the other characteristic state, the switch control means executes switching control that alternately switches the electric characteristics of the AC motor between the one characteristic state and the other characteristic state while shortening a time of the one characteristic state.

16. The inverter device according to claim **13**,

wherein the electric characteristics of the AC motor are switchable by switching the number of poles, and

wherein the switch control means executes switching control that alternately switches the number of poles of the AC motor between the number of poles for low speed and the number of poles for high speed on the basis of the rotation speed of the AC motor.

17. The inverter device according to claim **13**,

wherein the power supply means includes

power converting means including a switching element, and

phase-width modulation (PWM) signal generating means for outputting a PWM signal on the basis of a comparison between a voltage command and a carrier wave and controlling the switching element, and

wherein the switch control means executes the switching control in synchronization with the carrier wave.

18. The inverter device according to claim **17**, further comprising command generating means for generating the voltage command from a torque command on the basis of setting data including a motor constant and a control parameter,

wherein the switch control means obtains the setting data in accordance with the switching control by using a table or an arithmetic operation, and outputs the setting data to the command generating means.

19. The inverter device according to claim **13**,

wherein the power supply means includes

power converting means including a switching element, and

phase-width modulation (PWM) signal generating means for outputting a PWM signal on the basis of a comparison between a voltage command and a carrier wave and controlling the switching element, and

wherein the switch control means executes the switching control out of synchronization with the carrier wave.

20. The inverter device according to claim **13**, wherein the switch control means executes the switching control at a frequency higher than an output frequency of the power supply means.

21. The inverter device according to claim **13**, further comprising:

constant switch means connected to the switch control means so as to select and output a setting data in response to a winding switching signal from the switch control means to switch the winding state of the AC motor,

wherein the constant switch means selects and outputs the setting data among a low speed setting data for the low speed characteristics, a high speed setting data for the high speed characteristics, and a medium speed setting data for the switching control in response to the winding switching signal, and

wherein the AC power is made based on the setting data.

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